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INTRODUCTION.

During the summer of 1913 the Secretary of Agriculture established a board to reorganize the system of publications of the Department of Agriculture. In accordance with the proceedings of the board and the suggestions from representatives of the Weather Bureau, the "Bulletin of the Mount Weather Observatory" ceased to be published with the completion of its volume 6. Any subsequent contributions from the members of the research staff that would have been proper for that Bulletin will be incorporated in the Monthly Weather Review. The climatological service of the Weather Bureau will be maintained in all its essential features, but its publications, so far as they relate to purely local conditions, will be incorporated in the monthly reports for the respective States, Territories, and colonies.

Beginning with January, 1914, the material for the Monthly Weather Review will be prepared and classified in accordance with the following sections:

Section 1.—*Aerology.*—Data and discussions relative to the free atmosphere.

Section 2.—*General meteorology.*—Special contributions by any competent student bearing on any branch of meteorology and climatology, theoretical or otherwise.

Section 3.—*Forecasts and general conditions of the atmosphere.*

Section 4.—*Rivers and floods.*

Section 5.—*Bibliography.*—Recent additions to the Weather Bureau library; recent papers bearing on meteorology.

Section 6.—*Weather of the month.*—Summary of local weather conditions; climatological data from regular Weather Bureau stations; tables of accumulated and excessive precipitation; data furnished by the Canadian Meteorological Service; monthly charts Nos. 1, 2, 3, 4, 5, 6, 7, 8, the same as hitherto.

In general, appropriate officials will prepare the six sections above enumerated; but all students of atmospherics are cordially invited to contribute such additional articles as seem to be of value.

The voluminous tables of data and text relative to local climatological conditions that, during recent years, have been prepared by the 12 respective "district editors" will be omitted from the Monthly Weather Review, but will in future be collected and published by States at selected section centers.

The data needed in section 6 can only be collected and prepared several weeks after the close of the month whose name appears on the title page; hence the Review as a whole can only issue from the press within about eight weeks from the end of that month.

It is hoped that the meteorological data hitherto contributed by numerous independent services will continue as in the past. Our thanks are especially due the directors and superintendents of the following:

The Meteorological Service of the Dominion of Canada.
The Central Meteorological and Magnetic Observatory of Mexico.
The Director General of Mexican Telegraphs.
The Meteorological Service of Cuba.
The Meteorological Observatory of Belen College, Habana.
The Government Meteorological Office of Jamaica.
The Meteorological Service of the Azores.
The Meteorological Office, London.
The Danish Meteorological Institute.
The Physical Central Observatory, Petrograd.
The Philippine Weather Bureau.
The General Superintendent United States Life-Saving Service.

SECTION I.—AEROLOGY.

SECTION II.—GENERAL METEOROLOGY.

I.

FROST PROTECTION.

By W. J. HUMPHREYS, Professor of Meteorological Physics.

[Dated Weather Bureau, Jan. 20 and Nov. 20, 1914.]

INTRODUCTION.

The purpose of this paper is to point out the fundamental principles that make frost protection a practicable branch of atmospheric physics. The natural laws that should guide the design and use of apparatus in this connection will be emphasized, but the relative merits of the heaters and other equipment already put out by different manufacturers will not be discussed, nor will any effort be made, at least not in this paper, to describe anything new in equipment or method of frost protection, though clearly there still is plenty of room for improvement in both particulars.

GENERAL CONSIDERATIONS.

As every one knows, an object may exchange heat with the things that surround it in either of two ways: (*a*) By conduction in case of actual contact, facilitated by convection when immersed in a fluid, and (*b*) by radiation when separated by a diathermanous region. However, it is not always easy to determine *a priori* whether a given object under an observed set of conditions must lose or gain in temperature, for this obviously is a complex problem of area exposed, thermal conductivities, and coefficients of radiation and absorption. But whenever only two objects are concerned the result is never in doubt; whatever the ultimate mechanism or process of heat conduction and whatever the ultimate nature of radiation and of absorption, it appears to be universally true that the balance of heat exchange between them (and there always is such exchange), whether by the one process or by the other, is ever in favor of the coldest body. In other words, where there is only a thermal exchange it is always the cold object that gets warmer and the warm object that gets colder, and never the reverse; a warm object never gets warmer at the expense of the remaining heat in one that is already colder. To the physicist this is familiarly known as the second law of thermodynamics.

Now, the surface of the earth, whether soil, rock, water, or vegetation, is constantly exposed to both the above processes of heat exchange, one of which, conduction, is greatly facilitated by atmospheric circulation. Hence, normally, the lower atmosphere and the covering of the earth, whatever that may be, begin to grow warmer about sunup, continue to gain in temperature till sometime in the afternoon, when loss and gain are equal, and then gradually to get colder and colder till the following sunrise, when the whole cycle is repeated. As a matter of fact, there are numerous temporary conditions due to clouds, winds, rain, and the like, that more or less disturb the ideal regular sequence of thermal events, but nevertheless the average normal sequence is substantially as given, and the clearer the atmosphere and the stiller the winds the more nearly is this sequence followed.

By virtue of this alternate heating and cooling, and especially because the temperature of the surface layer of the atmosphere is chiefly controlled by the temperature of the greedily absorbing and freely radiating surface of the earth, it happens that in the lower atmosphere the change of temperature per given change in altitude greatly varies, particularly from day to night. Thus, when the weather is calm and clear the temperature up to some hundreds of feet, at least, during the day and especially of early afternoons, when vertical convection is active, may decrease almost at the adiabatic rate of approximately 1.6°F. per 300 feet. On the other hand, under the same conditions of clear skies and no wind, the air close to the ground at and before daybreak frequently is several, even many, degrees colder than the air at very moderate elevations. In extreme cases the atmosphere at an elevation of only 5 to 10 feet is as much as 5 to 10, or even more, degrees warmer than that on the surface. This surface temperature inversion, as it is called—that is, the increase instead of the decrease of temperature with increase of elevation—becomes less pronounced with increase of height, and while it may extend to an elevation of several hundred feet it seldom reaches any great altitude.

From the above it is obvious that the tops of open and sparsely foliaged trees, especially if rather tall, often are less subject to frost and more easily protected than are the lower limbs. On the other hand, when the tree is low and its outer foliage sufficiently dense to produce a protecting canopy over the under and inner branches, as is generally the case with orange trees, the difference between the free radiation from the exposed fruit and the restricted radiation from that which is covered may usually be sufficient, even when there is a marked temperature inversion, to subject the former and not the latter to the greatest danger from frost and freeze.

But how, returning to the main discussion, it properly may be asked, can any object—to be specific, the surface covering of the earth—become colder than either the soil beneath or the atmosphere a short distance above? As a matter of fact, this could not be a permanent condition, but it frequently is a temporary one, brought about as follows: When the air is still and clear, the surface of the earth, which is a good radiator, rapidly loses heat by radiation to and probably to some extent even through the atmosphere, and at the same time receives heat by radiation from the atmosphere, and to some extent also by conduction from the atmosphere, though mainly by conduction from the warmer soil beneath. But as the thermal conductivity of the soil is poor and that of the atmosphere many times worse, it follows, under the assumed conditions of clear skies and still air, that the surface temperature is largely determined by the tendency toward an equilibrium between the amount of radiation given out by the surface covering itself and the amount of radiation it receives and absorbs. But since the atmosphere is more or less diathermanous or transparent to heat radiation it follows that the interchange of heat by radiation between the surface covering and the atmosphere extends in some measure to great altitudes, where, of course, the temperature is very low, and also that some of the surface radiation may even escape directly to space whose effective

temperature, as a black body, or full radiator, is only a few degrees at most above the absolute zero. Hence the radiation *received* by the surface of the earth is only the little that would come from a full radiator at a very low temperature, and therefore, under the given conditions, the surface must lose more heat than it gains, and thus cool to a temperature considerably below that of the nearly adjacent atmosphere; it radiates to a great extent *through* and not *to* the adjacent atmosphere, and thereby temporarily cools to a lower degree.

It is this diathermanous property of the atmosphere that, in great measure, is responsible for the production of frost: and the resulting strong inversion of the vertical temperature gradient, perhaps more than anything else, renders frost protection through ordinary heating both an experimental and a commercial success. The inversion prevents the air, if but slightly warmed by a protection method, from rising to any considerable height quite as effectually as would a solid ceiling, and thereby limits to a comparatively small amount the mass of air actually so heated. In other words, the inversion of temperature makes it possible and apparently practicable to restrict the actual heating to as little as 1 or 2 per cent of the total atmosphere overhead, and that little the very part that it is necessary to heat in order to prevent frost.

Of course the ideal condition above assumed, of absolutely still air, never obtains in nature, and therefore when the lowest air is chilled through contact with the radiation-cooled surface it becomes more or less mixed, through movements of one kind or another (over valleys largely by air drainage from the sides), with the atmosphere of greater elevations, and thus the temperature inversion spoken of above always extends to higher levels than it would if there was no air movement and no air mixing.

Figure 1, representing a somewhat idealized typical case, will help to make some of these points clear. Here the usual temperature decrease with increase of altitude is supposed to obtain only above the 500-foot level, while below that level the temperature is supposed to decrease with decrease of elevation more and more rapidly quite to the surface of the earth. Obviously if, under these conditions, a wind of only one or two miles per hour should start up, the dense, freezingly cold air at the bottom would become mixed with the much warmer atmosphere a little way above, and the surface temperature would quickly rise to a degree safe from frost. Similarly, any artificial stirring up of the lower atmosphere, if of sufficient magnitude, would have the same effect of raising the surface temperature.

Figure 1 shows how it is that ordinary heating can protect from outdoor frost, and also indicates how this heat can most economically be applied. Let the temperature distribution be as indicated in the figure, and suppose the object is to keep the temperature of the lower atmosphere just safely above the freezing point. Clearly the most economical way to do this, so far as the consumption of heat energy alone is concerned, would be to have the entire surface warmed to the particular temperature in question.

Thus any portion of the surface air artificially or otherwise warmed—say to 34°F., that is, 2° warmer than the surrounding air—would rise, under the given conditions, to only about 30 feet, while a portion of air heated to 40°F. would tend to rise more than 250 feet, and thus produce a great deal of useless heating, since the atmosphere at such elevations could have but little influence on the surface temperatures. Artificial heating of the air to still higher temperatures, by large fires and the like, clearly is even much more wasteful of heat energy, and therefore the fuel or whatever is used to produce the heat. To be sure, the column of rising air over a big fire has no such high temperature as has the fire itself, and, besides, the turbulence it produces rapidly entangles it with much of the surrounding unheated air, but for all that its temperature is quite too great and the elevation to which it rises entirely too high for economical heating. Besides, the hot air from large fires would be ruinous to any vegetation it should touch and thus itself destructive of the very thing it was designed to protect. There is then every reason for having the heat well distributed and liberated at a comparatively low temperature.

But one properly asks, What is the minimum amount of heat energy, or of fuel to produce it, necessary under

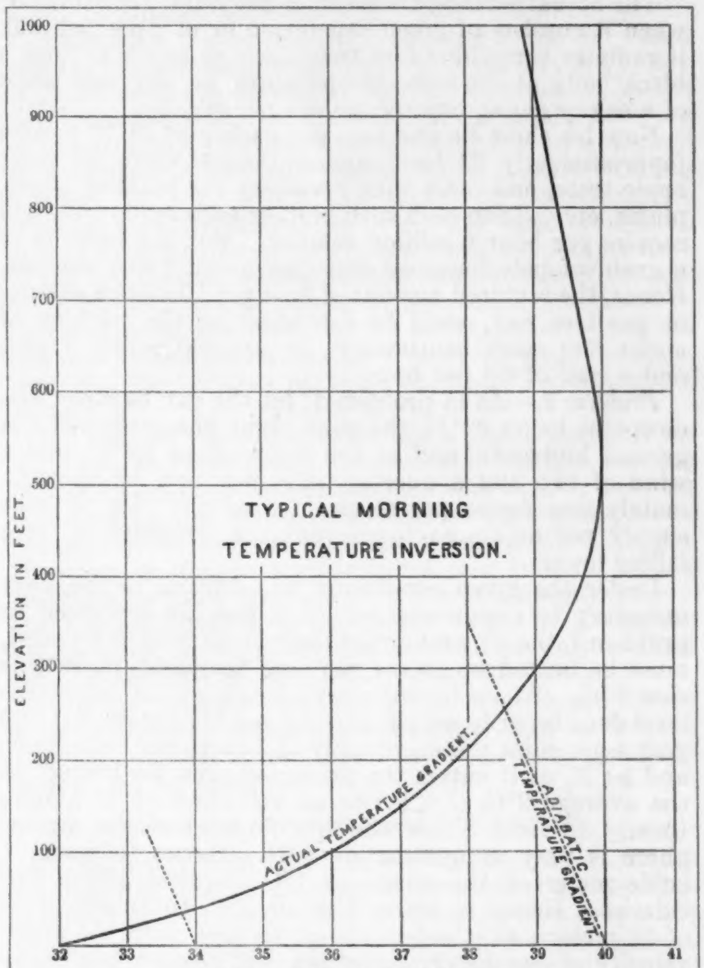

FIG. 1.—Illustrating the physical possibility of protecting outdoors from frost by artificial heating.

normal conditions, to prevent frost injury? This important question cannot be answered in terms of unqualified numerical values, because the actual conditions vary from time to time and from place to place. Still it seems worth while to assume certain more or less limiting conditions and to compute the corresponding thermal values.

Problem 1.—Let the sky be clear, the dewpoint below 32°F., the air calm, the time night, the surface of the ground horizontal and at the temperature 32°F. Find the rate of heat supply per unit area to prevent the temperature from falling lower.

These conditions are, of course, ideal and seldom very closely realized in nature, but they are definite and the problem therefore capable of approximate solution.

If, now, we assume no heat conduction from the soil beneath, an inaccurate but limiting condition, the essential thing necessary to the solution of this problem is the value of the "effective radiation" of the actual surface, or the difference between the thermal emission of the surface to and through the atmosphere and its absorption of incident radiation from the atmosphere and from the stars. For a black body or perfect radiator this is approximately known [1] and under the conditions assumed is roughly fifteen one-hundredths of a calory per square centimeter per minute.

It is unnecessary, presumably, to convert these values into their English equivalents, since the final answer will be given in both systems, metric and English.

The actual surface, however, is not a full radiator, but when it consists of green vegetation or of dark rich soil, it radiates something like two-thirds as much as does a black body at the same temperature, or, say, one-tenth of a calory per square centimeter per minute.

Now let there be one tree per each plot of 10 meters (approximately 33 feet) square—ample room for most apple trees, and more than necessary for peaches, pears, plums, etc. Then each such plot, or each apple tree, will require per hour 6 million calories. But the burning of a gram of petroleum oil averages about 8,500 calories. Hence, the required amount of heat per 10 meters square, or per tree, say, could be furnished by the burning of about 860 cubic centimeters, or approximately a pint and a half of oil per hour.

Problem 2.—As in problem 1, let the sky be clear, the dewpoint below 32°F., the time night, the surface of the ground horizontal and at the temperature 32°F., and a wind of two and a quarter miles per hour or approximately one meter per second. Find the rate of heat supply per unit area to prevent the temperature from falling lower.

Under the given conditions, in addition to the heat necessary to counteract radiation loss, as explained in problem 1, the air, as it enters the boundary to be warmed, must be heated up to the required temperature, in this case 0°C. To be liberal suppose the air to have sea-level density, or to weigh, at the given temperature, 1,290 grams per cubic meter, roughly 1¼ ounces per cubic foot, and let it, as it enters the protected area, be heated on the average 2°C. (3.6°F.) to an elevation of 12 meters (nearly 40 feet). Now the specific heat of the atmosphere is very approximately 0.24. Hence to warm 1 cubic meter of the given air 1°C. requires about 310 calories. Hence to warm the air 2°C. to an elevation of 12 meters, as it enters the given area with the given velocity of one meter per second, will require, per linear meter at right angles to its direction, approximately $2\times12\times310\times7{,}440$ calories per second, or the consumption of, roughly, 3.7 liters or 6.5 pints of oil per hour.

Let there be one tree to each 10 meters (nearly 33 feet) square, as before, and suppose the orchard to be 1 kilometer (a little more than three-fifths of a mile) square, and therefore to cover 247 acres, and the wind to be normal to one of the sides. Under all these conditions the necessary hourly consumption of oil to produce the required number of heat units to protect the entire orchard would be:

	Liters.
To counteract radiation	8,600
To warm the entering air	3,700
Total	11,300
Or 2,487 gallons.	

[1] A. Ångström, Astrophys. Jr. 37, p. 305, 1913.

Or, finally, assuming as before one tree per each 10 meters square, about 1.13 liters, or, very approximately, 1 quart per tree per hour.

Obviously the larger the area to be protected, provided it is compact, say approximately square, or else with its greatest length in the direction of the prevailing winds, the less important, relatively, is the initial heating of the entering air and the less the total fuel required per tree. Obviously, too, anything that checks the wind movement in the orchard makes it easier to heat. Hence small, scattered trees are harder to protect from frost than are large and spreading ones.

Of course a greater wind velocity than two and a quarter miles per hour, the velocity above assumed, would appear to necessitate a correspondingly larger consumption of fuel for the border or entrance heating. But this, presumably, is not true in practice, since probably even this velocity, certainly a greater one, would considerably mix the surface-cooled air with the warmer air above, and thereby decrease the amount of necessary heating. During a perfect calm the required border heating is zero; it is also zero when there is a fairly good breeze, and hence has a maximum value at some quite moderate intermediate velocity.

From the above considerations it appears that, under ordinary conditions, open-air protection from frost is not only possible but may even be economically practicable, and therefore, in what follows, the problem will be considered from the economic standpoint, and, for convenience, briefly under several distinct heads.

CONDITIONS FAVORABLE TO FROST.

In order successfully and profitably to protect an orchard against frost by means of artificial heating, whether a pit or pomaceous orchard in bloom, or a citrus orchard in fruit, it is necessary to know fairly accurately just when the heating is needed and when it is unnecessary, so that on the one hand no injury from frost shall be permitted, and on the other no useless expense incurred through response to false alarms. Hence it is urgently advisable to be in close touch with the Weather Bureau which systematically furnishes frost warnings to orchardists and to many others engaged in agricultural pursuits, especially to those who provide themselves with artificial means for heating their orchards, or otherwise mitigating or preventing frost injuries. Parties desiring to avail themselves of this service should make application to the Chief of the Weather Bureau or to the nearest Weather Bureau station, fully explaining their case and stating how they may promptly be reached by telegraph or telephone. Messages will be sent at the expense of the Government to local organizations and communities, provided arrangements are made for posting or otherwise effecting the general dissemination of the information. Messages to individuals at their expense can also sometimes be provided for under suitable conditions. Orchardists who cannot avail themselves of this service will find it to their advantage to inform themselves as fully as possible of the meteorological conditions that usually precede frost and thus be guided by their own knowledge of the subject. One or more alarm thermometers may, and indeed should, be placed in the orchard and set to any desired temperature; but it is well to have not only the immediate call of the alarm but also, for the purpose of making any small preparations that may be necessary, the timely recognition of well-known frost

indications. The most important and reliable of these are:

1. An evening orchard temperature of 40° F., or thereabouts.
2. Clear skies, to permit rapid radiation from the surface covering.
3. No wind, or very light, to avoid mixing the warm atmosphere above with the cold surface air.
4. Wind movement, so far as there is any, from a northwesterly direction.
5. Dewpoint below 32°F., to avoid the formation of a fog blanket, or the liberation of heat of condensation at temperatures above the freezing point.

But all these "signs" are only so many admonitions to be on one's guard in a matter where the price of success is eternal vigilance; they may be ever so helpful, but they are not infallible.

The moisture in the air is of special significance in this connection, and therefore it seems worth while to give some account of why it is so and of how it operates.

In the first place, an atmosphere containing a great deal of moisture does not let radiation from the earth pass through it nearly so well as does a dry one—it is not diathermanous, and therefore low humidity is essential to rapid surface cooling. Secondly, so long as the dewpoint remains above 32° F. frost can hardly form, since, as soon as the temperature of an exposed object falls below that of the dewpoint, vapor from the atmosphere condenses on it and in so doing converts its latent heat of vaporization into sensible heat and thereby prevents a greater temperature decrease. This relation of dew point to minimum temperature is not only obvious from elementary principles, but is also supported by the observational fact that at most places *frozen dew* is a thing of unusual occurrence.

To explain further: Since radiation is a surface phenomenon and therefore in amount is directly proportional to the area involved, while heat content, in the case of a uniform or homogeneous substance, is a volume phenomenon, it follows, in the case of cooling by radiation, that the coldest portion of an object is that portion whose exposed surface bears the greatest ratio to the mass it covers. Hence a sharp point or spine is the coldest portion of a body cooling as the result of its own radiation while the corners, edges, and flat surfaces follow in the order of increasing temperature. Hence both dew and frost collect most abundantly on exposed points, corners, and edges in the order named In the case of dew the surface tension of the water forces it to assume the shape of least area—that is, the sphere. Frost on the other hand, resulting as it does from the direct conversion of water vapor into ice, is a solid from the beginning, and therefore develops in the form of spicular crystals.

Now, if the temperature could fall considerably below the dewpoint, it necessarily often would happen that the droplets of dew formed in the earlier portion of the night would later be congealed into so many little balls of ice, on which a subsequent coating of hoar or white frost might or might not accumulate. But this phenomenon, which a sufficient drop in the humidity *after* the deposition of the dew may cause to happen, apparently does not otherwise occur. Hence it seems fair, both from elementary reasoning and from ordinary observation, to assume that the temperature of even exposed leaves and flowers will not fall appreciably below the coincident dewpoint. Hence a knowledge of the exact value of the current dewpoint is indispensable to successful frost prediction, and especially so since during "frosty" weather—that is to say, when the skies are clear and the atmosphere calm, the dewpoint usually remains nearly constant for several hours, and often much longer.

It must be remembered, however, that occasionally the dewpoint does change decidedly in the course of only an hour or two, and therefore that a high humidity in the early evening is not always a guaranty against a frost later in the night. Such changes naturally are most frequent, and hence the dewpoint indication least reliable, in regions that lie between the ocean on one side and arid mountains or plains on the other.

The simplest and most practical instrument for determining the dewpoint is the sling psychrometer. This consists of two thermometers fastened on a common frame and the frame in turn connected by a short flexible cord, link, or chain to a handle by which the whole may easily be whirled about at will. The bulb of one of the thermometers is bare and dry; the other is covered with a piece of clean unsized muslin which, when an observation is to be made, is saturated with clean water. As the psychrometer is whirled the water in the muslin covering evaporates, and thereby, if the covering is kept wet, cools to a certain temperature below which further whirling will not force it. When this minimum temperature is reached, and it usually takes but two or three minutes to obtain it, both thermometers are read; the temperature of the dry thermometer gives the temperature of the air; with this and the difference in the readings of the two thermometers, the dewpoint is easily found. [See the suitable tables, given in the Weather Bureau publication, No. 235, edition of 1900, entitled "Psychrometric Tables."]

For a given air temperature and a given dewpoint the difference in temperature between the dry and the wet thermometers of the psychrometer varies slightly with the barometric height in the sense that the greater the actual atmospheric pressure the less this temperature difference. However, as the variation in question is small, it will be sufficient for most practical purposes to use a psychrometric table adapted to a barometric height of 29 inches; and besides, for ordinary frost prediction only a small range in air temperatures will be needed.

Now that we have seen the conditions under which frost is most likely to occur it will be convenient to list and briefly to discuss a number of methods by which frost injury may be prevented.

SELECTION OF FRUIT AND OF REGION.

It has wisely been said that the best time to work corn is before it is planted, meaning of course that the most important factor in the production of a good corn crop is the preliminary preparation of the soil. In the same general sense it can truthfully be said that the best time to protect fruit from frost injury is before the orchard is set out; obviously by carefully considering what kind, or even variety, to grow and where to grow it.

Of course many things besides frost must be considered in establishing a commercial, or financially profitable, orchard, such as convenience to markets, kind of soil, shipping, keeping, and other qualities of the fruit and the like, but for all that in many cases climate is paramount and in every case important. An attempt to grow oranges in Ohio, for instance, or pears at Panama, would mean certain disappointment because of climatic conditions, regardless of proximity to market or any other local advantage there might be. Again, to illustrate with a less extreme and obvious case, it would be a commercial blunder, which fortunately no one makes, to attempt the production of prunes anywhere in the Eastern

United States, the region, perhaps, of their greatest market, simply because the climate does not suit them. To a less, though still important, degree this principle of climatic adaptation extends even to varieties of the same kind of fruit, and therefore if the variety is already selected, then the proper place in respect to climate, as well as soil and other factors, must be determined accordingly; or, if the place is already determined, the fruit and its variety best adapted to the climate and other conditions of the given locality should receive most careful consideration. Thus an early blooming and tender fruit should not be planted in a region where frosts are likely to occur late. In such a region there should be grown, if any, only hardy and late blooming varieties. This rule, everyone will admit, is perfectly obvious, but nevertheless it appears not always to be obeyed, and to its violation may well be attributed a goodly number of failures that need never have happened.

SELECTION OF LOCATION.

From the standpoint of frost protection the exact location is so vitally important that the difference of but a few hundred yards often determines between failure and success. The location should be such that:

1. The time of flowering shall be late.
2. The rate of morning heating shall be slow.
3. The air drainage shall be free and rapid.

The cold and therefore dense surface air formed on frosty nights drains away, under the influence of gravity, somewhat as water does to lower levels. Hence the expression "air drainage" in anology with water drainage. The importance of this last condition, air drainage, is so great as to justify, if it does not even demand, some account of exactly what it is and how it takes place.[2]

As already explained, during clear calm weather when the surface of the earth is warmed by sunshine and the lower air in turn by the earth the atmosphere up to from 2,000 to 3,000 feet at least is likely to decrease in temperature with increase of elevation very nearly at the adiabatic rate of approximately 1.6°F. per 300 feet. Above this level the rate of decrease is less. Under the given condition a quantity of air anywhere within the adiabatic layer, if slightly heated, would rise quite through this layer to and beyond its highest level before coming to a state of equilibrium, because although as it rose it would cool at the adiabatic rate, neglecting the always small loss of heat to the surrounding cooler air, this would be only the same rate of cooling as that of the atmosphere through which it was passing, and therefore if it started warmer than the adjacent atmosphere it would remain to the same extent warmer at every level than the newly adjacent atmosphere so long as the adiabatic of other equal rate of cooling applied to both. Similarly, a mass of air anywhere within the adiabatic layer, if slightly cooled, would continue to sink, remaining at every level colder than the surrounding air, until it reached the surface of the earth. If, however, the temperature gradient of the free atmosphere should be less than the adiabatic, say 1°F. instead of 1.6°F. per 300 feet, then a restricted volume of this air cooled to 1°F. below the temperature of the surrounding air would fall as before, but in falling 300 feet it would warm up roughly 1.6°F. while the temperature of the newly surrounding air would be but 1°F. warmer than that of the old, thus leaving still a difference of 0.4°F.; that is to say, the temperature of the falling mass would gain on that of the atmosphere through which it passed at the rate of only 0.2°F. per 100 feet. Hence, as it started 1°F. cooler than the adjacent atmosphere, to reach a level whose temperature is the same as its own, and therefore to come to equilibrium, it would have to fall 500 feet. In short, to small changes in temperature in the free atmosphere there usually correspond large changes in elevation.

Now the surface of the earth, and especially its covering of vegetation, loses heat by radiation much faster than does the atmosphere itself. Hence, after sundown, as Hann[3] and many others have explained, the surface layer of the atmosphere, rapidly grows colder and denser than the air somewhat above the earth and therefore tends to flow away to lower levels. This, too, in general, is the condition of the surface air at the next lower level, downhill say, and at the next and the next to the bottom of the slope. But, as water drainage tells us, there is everywhere among hills and mountains, except in occasional and restricted basins, a continuous more or less precipitous "downhill" all the way to a gently sloping valley or open plain; and hence in such regions surface cooled air must drain away or run downhill (the steeper the slope the more rapid the flow), substantially as does water, nowhere completely damming up, though often becoming sluggish, and nowhere forming frigid stagnant lakes save where water itself would form lakes.

As the cool, dense air flows downhill it of course slowly gains heat by compression but this does not necessarily mean that its temperature increases, for this dynamical heating may be, and on gentle slopes doubtless usually is, less than the simultaneous cooling it suffers through contact with the cold surface of the earth. But suppose, for instance, that the descending air has reached a place where it is at the temperature of the free atmosphere of the same level and therefore for the moment in equilibrium with it; even so it must continue to cool, through contact with the surface, more rapidly than the open air, because the earth and the plants that cover it are better radiators than is the atmosphere, and hence must continue its downward course toward a new place of equilibrium that is ever farther on.

In the special case, however, of a steep-walled basin in which water would form a lake, and, to a less extent, even in gently sloping valleys with steep sides, the drainage air from higher levels may and doubtless often does more or less overflow that of the lowest reaches, but this does not materially affect the general drift of air drainage nor greatly decrease its importance in relation either to frost formation or to frost protection. Whatever the details of this air drainage or however it may differ from time to time and from place to place, the lake of frigid air, if in a basin, or sluggish river, if a gently sloping valley is concerned, always has its surface or flood crest, so to speak, at the limit of the temperature inversion, or at that level both above which and below which the temperature decreases. Hence this level, more or less up on the adjacent slopes, necessarily is the warmest level, and therefore the one least subject to frost, or the one that marks the well-known and much-sought-after "thermal belt."

The above three conditions, late flowering, slow morning heating, and free air drainage, are, as a whole, best fulfilled on the northern or northwestern slope of a mountain or high hill, and therefore, so far as protection from frost alone is concerned this would be the ideal location. But then soil fertility and other conditions have to be considered, so that it can only be urged that the question of

[2] The reader's attention is invited to a different explanation of this so-called air drainage on p. 583.—[Editor.]

[3] Lehrbuch der Meteorologie, 3d edition, p. 446, Leipzig, 1914. [Hann does not discuss this species of air drainage critically. The above text simply conforms to the textbook versions, but the explanation is not satisfactory as it does not account for the inversion of temperature and the warming of the upper slopes.—EDITOR.]

frost immunity be given due—and that means very great—consideration.

Of the three conditions above mentioned, the third or free and rapid air drainage is by far the most important, and requires only that the orchard shall be located well up on the side of a mountain or hill. Even the top of a mountain or hill has distinct advantages as follows:

1. Low average temperature and consequent late flowering.
2. Complete air drainage and therefore comparative freedom from the effects of surface cooling.
3. The maximum of air movement and of air mixing.

There is, however, from the climatic standpoint, a limit, different for different regions, to the height at which orchards should be planted. The extreme and even the average temperature at points of greater and greater elevation soon becomes too low and the growing season too short for profitable fruit growing.

DELAY OF TIME OF FLOWERING.

The piling of ice and snow about the trees.—Obviously if the time of flowering could be delayed till after the latest killing frost, assuming there be left a sufficiently long growing season, the chance of having an abundant crop of fruit would be greatly increased. Indeed people have often sought to attain this end through the piling of snow or ice about the trees, but the results have never been equal to the expectations.

As a matter of fact the development of the bud, even to the opening of the flower, depends primarily on its own temperature and the temperature of the twig and the limb to which it is attached, and to only a very slight extent on the temperature of the roots. Now, since cold surface air remains close to the ground and even drains away wherever there is any appreciable slope, it follows that snow or ice piled about trees, however much it may chill the roots, can not greatly affect the average temperature of the twigs and the buds, nor therefore appreciably delay the time of flowering. It can not be said of course that no delay in the time of flowering can be produced in this way, for obviously the average temperature of the air that bathes even the topmost branches would be slightly decreased by any snow or ice piled about the trunk, and hence the time of flowering would certainly occur a little later. But it can be said that the probable delay is never sufficient to justify the necessary expense—that this method of preventing frost injury is commercially impracticable, and in all cases more of a delusion than a success.

Spraying with whitewash.—The object of this process is to cover the twigs and buds with a harmless white coating which, because it strongly reflects solar radiation instead of absorbing it, will keep down the average twig temperature and thereby delay the date of blossoming. Now a coating of lime whitewash besides being cheap and rather easily applied by means of a suitable spray seems to be harmless and certainly is a good reflector and therefore a poor absorber of solar radiation. Nevertheless the temperature of the twigs and of the buds can not greatly differ from the temperature of the air that surrounds them, and therefore it would seem that this particular method also of delaying the time of flowering does not promise much success. Just exactly what small effect it would have does not appear to have been definitely established, but it does not look promising from a commercial standpoint unless indeed the coating of whitewash should be beneficial for some other reason, such as the killing of insects, the prevention of fungus and the like.

FROST PREVENTION.

Material of ground covering.—Since the temperature of the atmosphere at and near the surface of the earth is largely determined and controlled by the temperature of this surface itself, it follows that where the ground covering is a good radiator the temperature of the air will fall lower, other things being equal, than it will where the covering is a poor radiator. Hence the probability of frost can be somewhat reduced by covering the ground with a poorly radiating material. Indeed it has already been the custom for a number of years to cover certain cranberry grounds with white sand as a means of reducing the danger from frost, and it is quite certain that part of its efficacy in this respect, though only a part, is due to its low power of radiation. However, to cover an entire orchard with this or any other poor radiator probably would seldom be practicable. Besides, such a ground covering at best can never be more than a slight and very imperfect protection from frost.

Condition of ground covering.—Obviously there never is any occasion to protect either fruit or flower from frost when the ground is frozen—either the trees have not yet come into bloom or else the fruit is already killed. Hence, whenever there is any need to protect from frost the earth is unfrozen, and contains more or less heat to spare. Clearly, then, this soil heat should be made available, and to this end the soil *bare* and *tightly rolled.* Bare because weeds and other trash not only are free radiators as a rule, but also to a great extent insulate or render unavailable the ground heat, and tightly rolled for the purpose of rendering the soil more compact and therefore a better conductor and better warmer of the air above.

In many cases, however, it is not practicable to utilize the ground heat to best advantage, owing to the necessity of covering the orchard (citrus) during the frost season with some good humus-producing crop. But this practical method of obtaining the necessary humus does not alter the general fact that ground heat is valuable in warding off frost, nor that this heat is best secured from a bare and tightly rolled surface.

Whether the soil should also be moist seems doubtful. The water would of course have much heat of its own, and besides it would increase the thermal conductivity and thus bring a larger amount of heat to the surface. But, on the other hand, there would also be an increased amount of evaporation with its attendant cooling, so that the net result presumably might be either a heating or a cooling depending upon the rate of evaporation directly, or indirectly upon the surface temperature, absolute humidity and wind velocity.

Deflection of air drainage.—Clearly if cold air drains into an orchard danger from frost is somewhat correspondingly increased. Hence in some localities it might be worth while to run a closely planted hedge, a tight plank fence, or even a stone wall along the upper side of the orchard in such manner as to deflect the maximum amount of cold air away from the trees. Of course this refinement may seldom be commercially practicable or even very effective, but the vital importance of air drainage justifies its inclusion among the possible means of preventing frost.

Forced air drainage.—Since air drainage is so important as a means of preventing frost, it follows that where natural drainage is obstructed artificial or forced drainage, if sufficiently abundant, might be substituted with good effect. That is to say, with good effect so far as

preventing the frost is concerned, but the cost of the plant necessary to produce this drainage, and the cost of operating it, obviously rule it out absolutely as a commercial process.

Mechanical mixing of the atmosphere.—As already explained, frost, at the time of year when it is likely to injure fruit, does not often occur when there is wind sufficient so to mix the lower atmosphere as to prevent excessive surface cooling and therefore a temperature inversion. Hence, on perfectly still nights, vigorous mechanical mixing of the air, if on a sufficiently large scale, would have results similar to a natural mixing by the winds.

But this process, too, like forced drainage just discussed, clearly is totally out of the question as a commercial proposition, and is mentioned here only further to emphasize the narrow limits within which the problem of commercial frost-prevention is restricted.

Spraying with water.—As already explained, when the amount of humidity in the atmosphere is sufficient to put the dew point above 32° F., frost can hardly occur. Hence it would seem that a number of spraying fountains scattered through an orchard might raise the dew point above the freezing stage and thus avoid the formation of frost.

However, the problem is not so simple as it looks, nor is the prevention of frost by this means an *a priori* certainty. In the first place the spray, to be effective in the manner explained, must evaporate, and that means cooling, or the conversion of just as much heat from the sensible to the latent stage as later can be set free by condensation. Again, if the spray falls directly on the trees when in bloom great injury may be done to the flowers by washing away the pollen. Of course no such objection applies after the fruit is formed. Spraying with water, therefore, apart from the expense and difficulty of putting it in operation, does not seem to promise well as a means of preventing frost. However, further experimentation in this line seems desirable.

Screening against loss of radiation.—Since the low night temperature that threatens or even brings frost, results from more or less free radiation from the surface covering of the earth to and through the atmosphere above, it follows that any intercepting screen, *if itself a poor radiator*, will more or less effectively prevent the formation of frost. This explains why frost seldom occurs on cloudy or foggy nights, and why a covering of papers or of cloth partially protects plants of any kind from freezing.

It must be distinctly remembered, as above implied, that it will not do to use just any sort of covering. A rusty tin can or bucket, for instance, turned over a plant increases its chance of freezing. In fact it occasionally happens that plants "protected" in this manner are entirely killed while the unprotected ones remain uninjured. The explanation of course is simple enough. The rusty tin can is a better radiator than is the soil and hence it, and the air within it, becomes even colder than the ground or the surface air round about.

There are, however, many substances, such as paper, cloth, and wood that are, in various degrees, poor radiators, and these may be used as screens to great advantage, particularly in the case of small fruit, beds of tender vegetables, and the like, where neither the cost of the screens nor the labor of handling them is prohibitive. Clearly though, the screening of an orchard, whether only tree by tree or the entire area, is quite another thing from screening a flower bed or berry patch, and obviously in nearly if not quite all cases is commercially impracticable, both because of the original cost of an efficient screen and because of the labor necessary hurriedly to put it in position. To be sure the screen might be a lattice covering permanently in position, but the obvious disadvantages of such a covering, original cost, cost of upkeep, interception of sunshine and doubtless still others, are so great that manifestly it can have but little practical use.

Smudging.—A pall or canopy of smoke, or smoke and steam, spread over an orchard by burning such stuff as damp leaves, stable manure, wet straw and the like, among the trees, especially on the windward side, constitutes a moderately effective screen against radiation losses. The process of securing this screen also supplies more or less heat to the surface air and still further protects the orchard from frost. Smudging, then, if properly carried out, seems to be not only scientifically sound but also economically practicable.

Dry heating.—As explained in the first portion of this paper and illustrated by the two numerical problems, large orchards usually can be protected from frost by a properly distributed dry heat, and that too at a small fuel cost per tree. What the fuel should be, whether wood, coal, oil, or even gas, must depend of course upon such things as cost, availability, convenience of use, and the like. In most places crude oil seems to have more advantages than does any other fuel, though, if burnt with a smoky flame, it has the very distinct disadvantage of smutting the fruit, an objection that applies essentially to citrus orchards in fruit and not to orchards in bloom. It also smuts houses and, in general is objectionally dirty.

Dry heating for the protection of an orchard against frost should be carried out in the largest practicable number of small units, however the heat is supplied, whether by direct combustion of some suitable fuel, by the circulation through pipes of warm water, by the delivery of warmed air to the individual trees, or by any other process. A few strongly heated centers both endanger the nearest trees and also, through the strong local convections set up, send most of the heat to levels where it will be of little or no service.

Just how the oil pots or other heaters should be constructed is another problem, and one which obviously may be more or less excellently solved in innumerable ways.

Irrigation.—Flooding of the ditches in a cranberry bog has long been practiced as one of the most effective means of warding off a threatened frost. The great heat supply of the water prevents the temperature of the surface air from decreasing nearly so rapidly and therefore from reaching so low a temperature as it otherwise would. Now, just as irrigation is effective as a means of preventing frost in a cranberry bog, so too it would be effective in warding off frost in an orchard. But then comparatively few orchards are so situated that they can be easily and cheaply irrigated whenever occasion may require. Besides, it must be remembered that a wet soil, whether wet from rain or from irrigation, warms but slowly by day, and even cools when the weather is windy and cloudy, so that if the supply of irrigation water is small, a single irrigation, even if it should prevent the frost of the first night, might render a later frost all the more likely. Irrigation, then, even in the few places where it could be used, is rather a dangerous weapon to employ in fighting frost, one liable to become a meteorological boomerang as it were. A further objection to irrigation is the fact that it is likely to interfere with other forms of artificial heating by rendering any necessary hauling of fuel difficult if not impracticable.

FROST CURE.

In a measure frost injury to flower as well as to fruit may be cured by slow thawing. Probably it would be much more accurate to say that frost injury, at least in many cases, is caused rather by rapid thawing than by the original freeze; though it must be admitted that just how fruits, flowers and plants actually are injured by low temperatures is not perfectly understood. At any rate when fruit or flower is very slowly thawed out it often appears to be uninjured. Hence even after frost has covered an orchard it sometimes is possible, especially by the use of a heavy smudge on the windward side, so to shut off the morning sunshine and thereby so greatly to decrease the rate of thawing that but little injury follows. Clearly, though, this is a risky practice. It is another case where the old adage, "an ounce of prevention is better than a pound of cure," applies with full force.

CONCLUSION.

The most important thing in relation to frost protection is the proper adaptation to each other, at the time of planting, of fruit, climate, and location, with reference especially to time of flowering, probable dates of latest and earliest killing frosts, and freedom of air drainage. In this way natural frost immunity may generally be secured.

In places not so favored artificial heating often may be used on a large scale and with commercial success to prevent frost, the strong temperature inversion of a frosty night serving as a ceiling that restricts the heating to a thin surface layer of the atmosphere, provided, of course, that the heating is diffuse and the temperature of the air raised only a few degrees.

The meteorological principles and the physical laws involved in the problem of frost protection seem reasonably clear, but the question of economy introduces so many and such uncertain factors that its commercial practice must be difficult if not impossible completely to standardize. The best practice at one place and under one set of conditions presumably will differ in detail and may even differ in method from that of some other place under other conditions. To each region, and even to each orchard, pertains its own problem, which rational or scientifically guided experimentation alone can approximately solve.

In closing I wish to thank Mr. J. W. Garthwaite, of Corona, Cal., for his kindness in reading the manuscript of this article and for his generosity in putting several valuable suggestions at my disposal.

II.

UTILIZATION OF FROST WARNINGS IN THE CITRUS REGION NEAR LOS ANGELES, CAL.

By FORD A. CARPENTER, Local Forecaster.

[Dated Weather Bureau, Los Angeles, Cal., Jan. 22, 1914.]

CONTENTS.

(*a*) *Introduction.*—For 20 years or more oranges and lemons have been successfully raised in southern California, but it is only within the past decade that strictly scientific and up-to-date methods have been used in raising and selling the citrus products.[1] This has brought about a standardization of both the fruit and the marketing. Improved and more expensive methods of preparing the land, irrigating it, and planting with high-grade stock, as well as constant vigilance in fumigating and spraying for fruit pests, have necessitated better facilities for packing, handling, and selling the product. The frost menace made its first appearance in 1896, when some regions escaped without serious damage. The orchardists in the frosted localities immediately began experimenting with various preventives, thus antedating the frost protective work of the deciduous fruit growers in Colorado, Washington, and Oregon. The frost of two years ago increased the number of heating appliances, and the severe freeze of last year brought the entire industry in all portions of California face to face with an added hazard. It has been said that the freeze of 1913 raised a new crop of prevaricators, which may be divided into two classes—those who claimed that their district was frostless and others who declared that their district suffered destruction. A year has passed, and it is not too optimistic to say that the truth is a little nearer the former than the latter. Those orchardists who, anticipating severe frosts, had provided themselves with artificial heating devices realized handsomely on their additional investment, for the short crop of oranges, lemons, and grapefruit brought excellent prices. Fruit growers in the citrus region of California now add to their fixed expense account a liberal allowance for oil or coal pots, storage of fuel, instrumental equipment, and quarters for emergency labor. One million approved oil pots are now scattered over the citrus region in southern California.

It is the object of this memorandum report to give a brief description of the character of the country, its elevation and configuration, the variation in the exposure to sunshine and wind, and the variations in temperature that are caused by local environment. It is proposed to treat very briefly the distribution of lemons and oranges in differing climatic areas. Weather conditions causing frost will be briefly discussed. The manner in which warnings are issued by the local office of the Weather Bureau at Los Angeles, and how they are utilized by the fruit growers in this district will be considered in detail,

[1] Citrus crops of California for 1913; annual estimate by the Riverside Daily Press, Jan. 20, 1914; reduced to percentage by F. A. Carpenter.

Counties.	Orange.	Lemon.
	Per cent.	*Per cent.*
Redlands district	12	0
Riverside	10	0
Pomona	12	6
Ontario	11	8
Azusa-Glendora	9	6
Orange	7	9
Highland	6	0
Covina	5	0
Placentia, Fullerton, Rialto	11	....
Rialto, San Fernando	....	6
Whittier, etc	6	11
Ventura	5	15
San Fernando, Pasadena	4	....
Rialto, San Fernando, etc	....	6
San Diego, etc	2	....
Pasadena, San Diego, etc	....	10
Corona	0	12
San Dimas	0	9
Santa Barbara	10	8
Totals	100	100
SUMMARY.		
Northern California	14	0
Southern California	86	100
Crops, respectively, by carloads	35,270	3,900

Total, 39,170 carloads, or about 80 per cent of normal.

illustrated by a number of photographs made especially for this report. The essentials of orchard heating devices will also be described.

(b) *Character of the country.*—The citrus district of the country adjacent to Los Angeles covers a thin crescent-shaped region, having Santa Barbara for one extreme and San Diego for the other, with the San Bernardino Mountains marking the eastern limits (see fig. 1). This territory covers about 200 miles northwest to southeast and 40 miles in width. Much of the coast region, while possessing the climate, does not have the requisite soil. In elevation this district ranges from tidewater to 1,000 feet above sea level. Although the exposure is to all points of the compass, relative regional advantages are determined by the configuration of the country.

(c) *Variations in grove location.*—Citrus groves are located with a western exposure on the coast near Santa Barbara (fig. 2), with a southern exposure at Santa Paula (fig. 4), a northern exposure at Corona (fig. 32), a western exposure in portions of Redlands and Riverside; valley locations in San Fernando (fig. 12), and on either side of river washes as at Fillmore (figs. 8, 9, and 10), and in the foothill district of Pasadena (fig. 14).

(d) *Variations in temperature caused by local environment.*—It is needless to state that these widely different exposures give varying temperature values. It is often the case that what promises to be a general frost will give orchard thermometer readings varying from 26° to 56° in this district. A descending wind over the San Bernardino Mountains, or a change from the land to the sea breeze at Santa Barbara, Santa Paula, Chula Vista, or other coast localities, will change the temperature as much as 15° in as many minutes. On the other hand, a sudden cessation of wind in the lower districts will check natural drainage and lower the temperature many degrees in a very short space of time. An interesting fact in connection with differing climatic features in this region is noticed in the transportation of lemons and grapefruit from the region where they are grown to the more even and cooler coast climate. Lemons grown on the warm hillsides in winter are frequently sent a hundred miles north for natural cold storage and curing.

(e) *Pressure conditions which cause frost in Los Angeles and vicinity.*—There are three varieties of pressure distribution that bring frost to this locality. Named in order of their frequency they may be considered as follows: First, well-marked and general high-pressure conditions prevailing over the entire coast, such, as for example, preceded the phenomenal freeze of January 5, 6, and 7, 1913. Second, the advent of a small but energetic high area to the coast south of Point Conception. The formation of this area has to be carefully watched. It will frequently impinge on the coast in the vicinity of Los Angeles. If another high area happens to be in control of the weather over the western half of the country, this southern area will aid in the extension of the attendant northern low area, with accompanying gradients, resulting in heavy local rain. The southern high will then drift eastward, after the northern low moves northeastward, and it is then that the sky clears and strong radiation ensues, producing frost in the citrus region.

A third condition, and one that sometimes brings unexpected cold, is when an immense continental high is apparently too far to the eastward to affect the temperatures, but a slight weakening of the northwestern low area will allow the influence of the high to be felt by causing a sudden fall in temperature. The last-named condition obtained on the only occasion when emergency long-distance frost warnings have been issued during the present month. These warnings were issued from the Los Angeles office on the evening of the 12th to all citrus districts in the vicinity. Temperatures of freezing were generally reported the next morning. Pomona reported 27°F., Riverside 32°, and San Bernardino 26°, which were the lowest of the season of 1913-14 up to the present date (Jan. 22, 1914).

(f) *How frost warnings are issued from the Los Angeles office.*—Warnings of frost are worded according to their expected severity such as "light frost in exposed places," "light frost," "heavy frost in lower levels," "heavy frost," "severe frost," "killing frost," "killing frost; growers should fire early." These warnings are printed on forecast cards and on the maps and mailed at half-past 9 a. m. to about a thousand addresses. The 11 a. m. and later editions of the evening papers print regular weather "stories" during the season, in which the local forecaster is quoted in full, and generally with much accuracy. The largest long-distance-telephone company distributes the morning forecasts free of charge to every "central" telephone office in southern California, so that every grower can secure the morning weather report. Special long-distance warnings are sent to responsible distributing centers in all districts north of Escondido, (1) when the morning forecast happens to be too late for the mails, (2) when evening conditions have changed making a special additional warning necessary.

(g) *Utilization of frost warnings.*—The cooperative associations throughout this district have such an excellent system that all information received from the Los Angeles office is immediately put to the best use.[2]

Individual growers depend to a great extent on the official warnings, although all have their own alarm thermometers and instrumental equipment which in addition allows them to amplify the warning. The writer happened to be at a large citrus headquarters when a frost warning was received The military exactness and promptitude of the association in delivering and executing orders for the "firing squad" (fig. 5) gave evidence of the successful working out of a splendid system. In all districts nothing is now left to chance; the management of the majority of the big orchards reminds a visitor of the scientific accuracy observed in a Government agricultural experiment station. At Corona a checking-up system is employed for the benefit of local orchardists.

(h) *Orchard protection by heating devices.*—Where there is one coal basket in this district there are over 1,000 oil pots, so popular has become the oil system of heating. The plan is to place a 7-gallon oil pot to each tree, with a double row of pots around the exposed side of the grove. The improved down-draft pot (figs. 4, 6, and 32) will last from 6 to 10 years if given good care. It is very economical, as the fire can be regulated depending on the variation in air temperature. At Santa Paula it has been found that temperatures as low as 12° can be negotiated

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[2] The following (fig. 16) is a sample of letters sent out by the lemon and orange associations in the Los Angeles district:

ONTARIO FROST PROTECTIVE LEAGUE.

ONTARIO, CAL., *December 6, 1913.*

SIR: Arrangements have been made with the U. S. Weather Bureau station at Los Angeles to telephone any special frost predictions that may be made in the afternoon or evening. The local telephone company have your name and these messages will at once be telephoned to you.

Whenever the temperature falls to 35° F. lemon growers will be notified in order that they may be on the alert to personally watch conditions.

Whenever the temperature reaches 29° any time before midnight orange growers will be warned. If the temperature reaches 32° at midnight and whenever it drops to 28° up to 4 o'clock a. m. orange growers will also be notified.

As a dangerous condition does not exist when there is much humidity in the air, even at these temperatures you will also be notified of this fact, and growers must then use their own good judgment whether to fire up or not.

As the telephone operator has to call up quickly a great many people, *please do not ask operator any questions* as she can tell you nothing more than the message she has been directed to give. *This is important.*

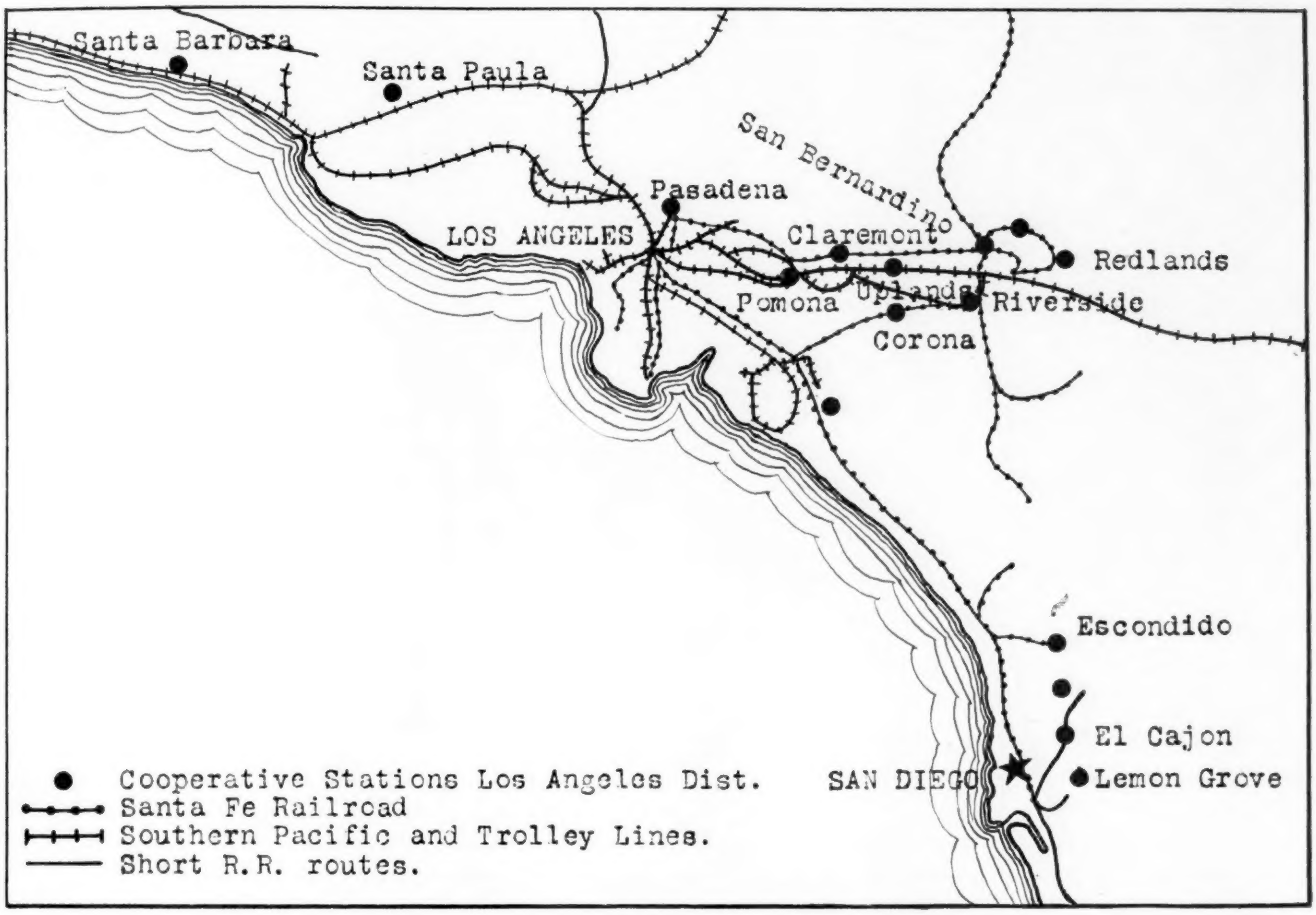


Fig. 1.—Map of the citrus fruits district about Los Angeles, Cal.

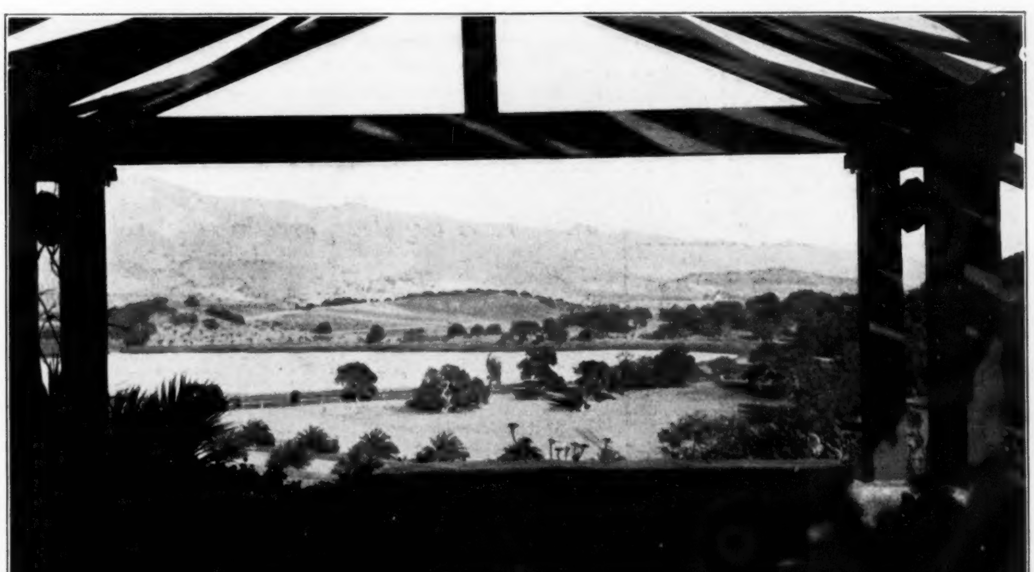
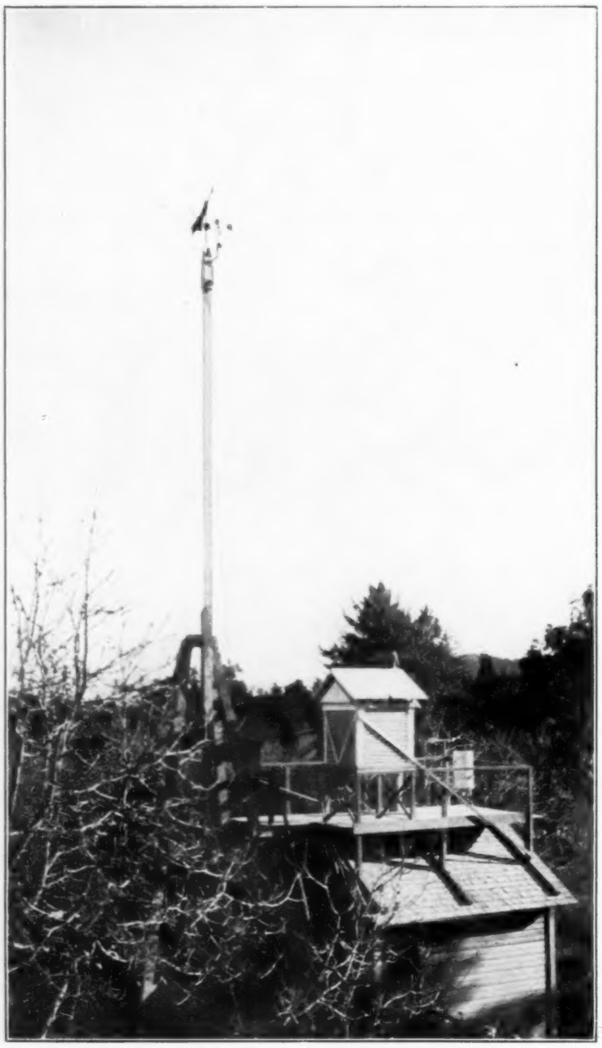


Fig. 2.—A typical Santa Barbara (Cal.) landscape. View is from the pergola of the Potter Country Club, looking toward the San Rafael range (6,500 feet). A lake is in the middle distance, the lemon groves are beyond the rounded oak-clad hills.

FIG. 3, § IV.—Photograph of the dust cloud accompanying "norther" conditions. (Photographed Mar. 16, 1914.) This depicts the birth of a "norther" in the Los Angeles district. This typical dust cloud always marks the beginning of "norther" conditions. The snow-capped peak in the center is Mount San Antonio (10,080 feet) and its range is about 25 miles distant, due north. The dust cloud, where it is beginning to reach ordinary intensity, is over the town of Pomona, Cal., which is about 16 miles distant. As the wind warms up to its work the long, horizontal streamer reaches the height shown in the northwestern portion of the photograph. Although the wind direction is from the east the western portion of the country first shows the dust cloud at its maximum density. The dust billow in the west [on the left of the center of this view] was raised in about one hour; in less than two hours the mountain range entirely disappeared. This condition has occurred very seldom this year (1914), but during the season of 1912-13 it was an almost continuous performance. Figure 4 on page 573 presents the station weather map on the day on which the above photograph was taken.



A.

B.

FIG. 3 A AND B.—Weather Bureau cooperative station at Santa Barbara, Cal. *A*, View of the station from a neighboring tower. This shows the anemometer, wind vane, instrument shelter, sunshine-recorder, and tipping bucket gage. *B*, A side view of the same station as seen from the ground. The thermometers in the shelter are 24 feet above the ground.

FIG. 4.—One of many orchard instrument shelters on the Lemoniera Ranch, Santa Paula, Cal. The thermograph in this instrument shelter read several degrees higher than thermometers attached to trees. Investigation showed the cause to be the proximity of the irrigation standpipe. In the shelter the temperature was 36° F.; on the ground near the trees, 30°; just inside the edge of the pipe seen standing near the supporting frame, 43°. The illustration also shows the method of using pots close together to protect the outside of the grove. The superintendent, Jas. D. Culbertson, writes: "During the season 1912-13 the expense of protection amounted to the following figures: Total investment for 500 acres, $91,225.92; cost of equipment, $182.45 per acre; annual deterioration and maintenance, $33.34 per acre. These figures do not include operating expenses."

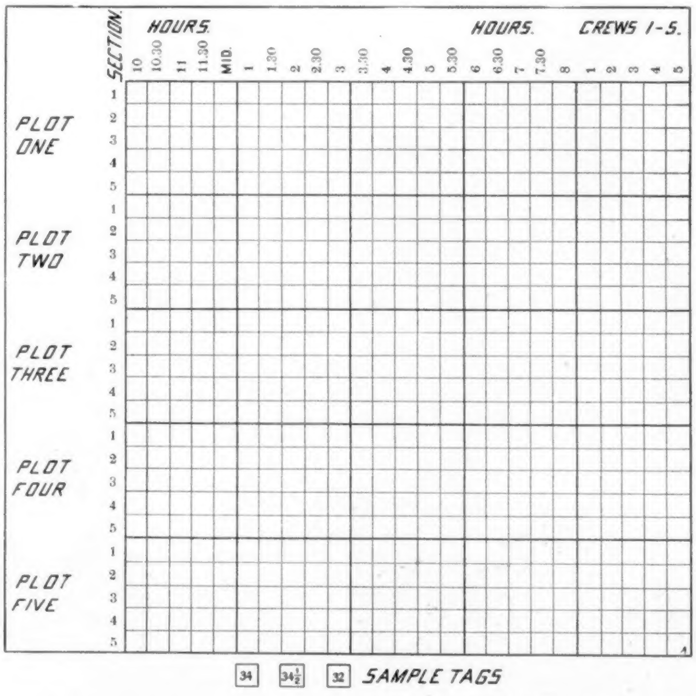


FIG. 5.—A "temperature board" for the Lemoniera orchards, designed by Foreman Perry, of the Lemoniera ranch. This blackboard chart is located at the ranch library. Columns show the hours from 10 p. m. to 8 a. m., divided into half hours. Horizontal divisions are plots and sections. Crew distribution is shown at the extreme right-hand edge of the chart. Cards bearing boldface printed figures in degrees and half degrees are hooked into the squares from which temperature reports have been received by telephone. If the temperatures approach 30° F. in any sction, a firing squad is sent out and pots are lighted. Great importance is attached to firing early. The general experience in the Los Angeles citrus district shows that fuel and labor must not be spared in keeping the temperature from *reaching* the danger point.

FIG. 6.—A young lemon grove at Santa Paula, Cal. This view shows the distribution of oil pots to protect the trees of a young lemon orchard. Each tree is protected by a pot having a capacity of 7 gallons of oil. The pot can be regulated to burn at the rates of 1 pint to 1 gallon per hour. This is the popular pot of this district. It costs $1.04, and will last, with care, 6 to 10 years. It is estimated that the equipment of the Lemoniera ranch will successfully cope with an outside temperature as low as 12° F.

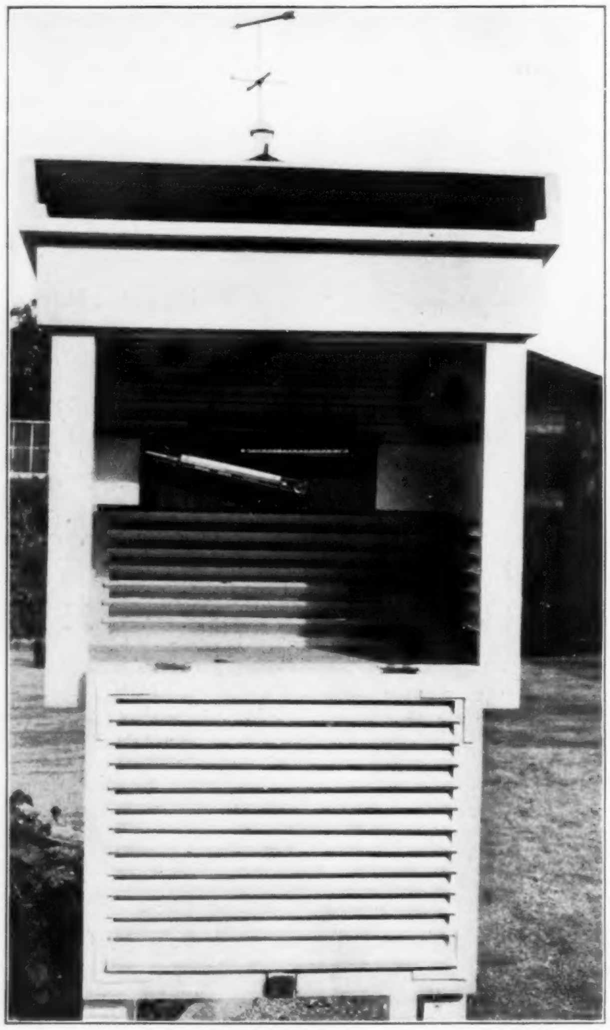


FIG. 7.—View of the instrument shelter (open) at Fillmore, Cal. This is one of perhaps a hundred such privately equipped thermometer shelters scattered over the citrus fruit region adjacent to Los Angeles, Cal.

FIG. 8.—View of Fillmore Bridge. Orange groves are to be observed from the foothills to the edge of the river wash. The "wash" in this locality is wide and drains the greater portion of this citrus region. On the north slope of this valley growers are experimenting with glass coverings for several acres.

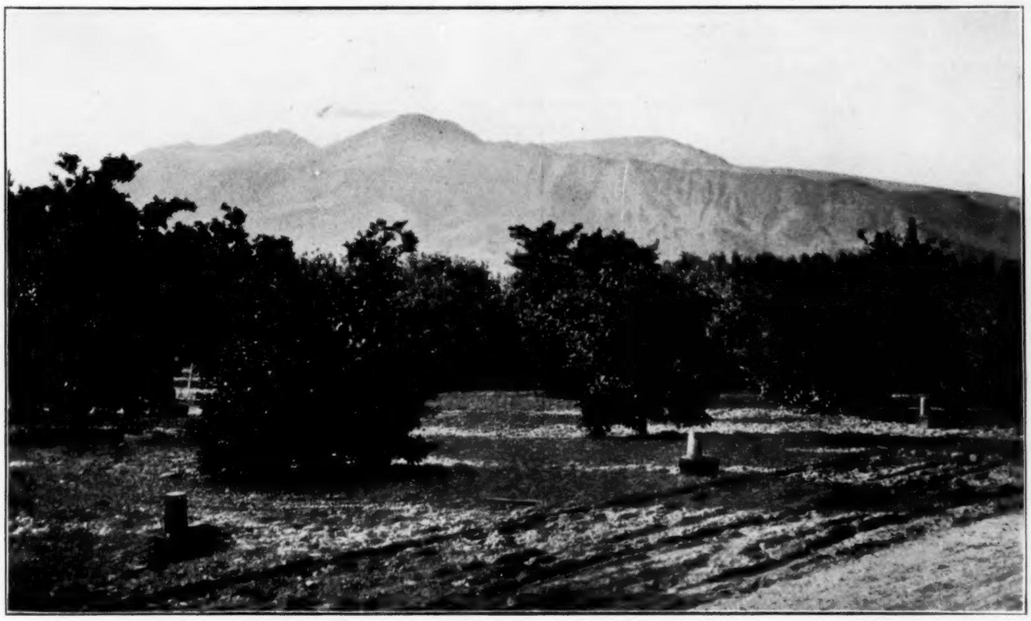


FIG. 9.—A lemon orchard at Fillmore, Cal. In the distance is seen the Topatopa Mountains. The old-style oil pots shown in this photograph carried this grove through safely and with but small expenditures of labor and oil. This was doubtless due to the excellently drained, extensive "wash."

FIG. 10.—Fillmore High School, set in an orange grove. It is not unusual in the citrus district to find schoolhouses in orange orchards. It is seldom, also, that orange or lemon groves are fenced off from the highway. [Figure omitted.]

FIG. 11.—Portion of the San Fernando Valley. Flat valley land not suited to citrus growth because of the nocturnal settling of cold air and the brisk winds of the day. This land, where planted, is largely in peaches and vegetables. [Figure omitted.

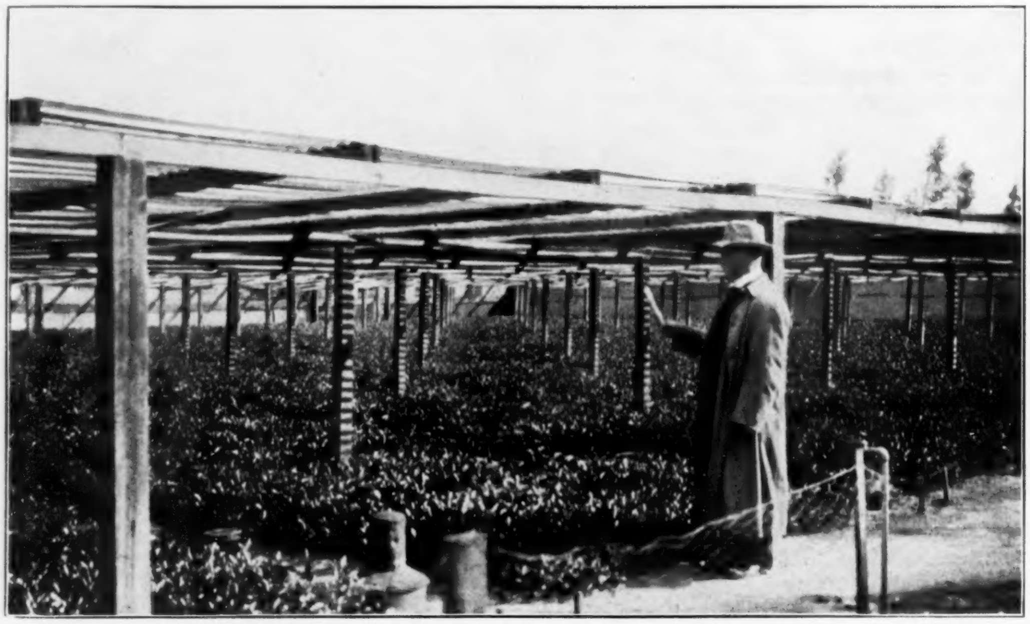


FIG. 12.—A lath house protecting the lemon nursery of T. J. Walker at San Fernando, Cal., in the upper San Fernando Valley. In this lath house temperatures average 4° F. higher than those in the unprotected orchard near by. Only a few fire pots are needed in the lath house.

FIG. 13.—Thermometer exposure at the Pasadena station, located in a deciduous fruit orchard, belong to Cooperative Observer E. R. Sorver, secretary of the Pasadena Board of Trade. [Figure omitted.]

FIG. 14.—Lemon grove in Pasadena, Cal. One of hundreds of 20-acre lemon groves owned and managed by retired professional men. Mount Wilson (5,000 feet) is in the background. [Figure omitted].

FIG. 15.—Lemon grove at Upland (Ontario district), Cal. A lemon grove of 40 acres a Upland. San Gabriel Mountains are in the distance. [Figure omitted.]

FIG. 16.—[See footnote 2, p. 570.]

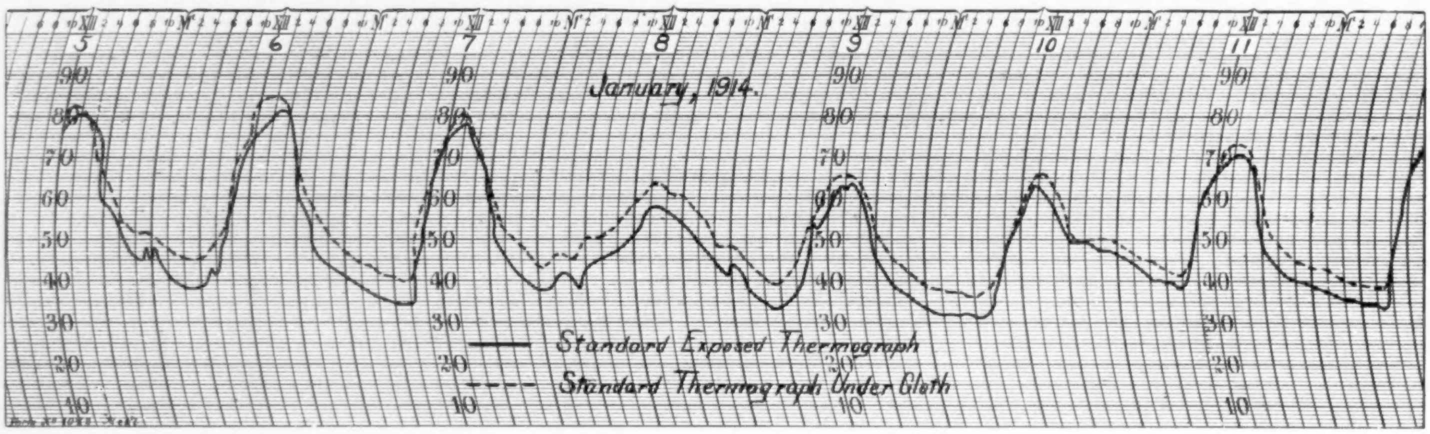


FIG. 17.—Thermograms (Richard) at the Pomona cooperative station, January 5–12, 1914. Cooperative Observer J. E. Adamson erected portable "horses" in a selected acre of his orchard and, with rollers, covered the tops of the trees. The material used was tobacco cloth; 5,000 yards of material were required. The cost of such protection was $265 for the acre. A standard Richard thermograph was exposed in a Weather Bureau standard cooperative shelter located in the center of this covered acre. The thermograms snow the differences between the standard thermograph exposed in a shelter similar to that shown in figures 18 and 33.

FIG. 18.—Thermometer exposure at Pomona, Cal. One of a number of thermometer shelters at Cooperative Observer J. E. Adamson's orchards. [Figure omitted.]

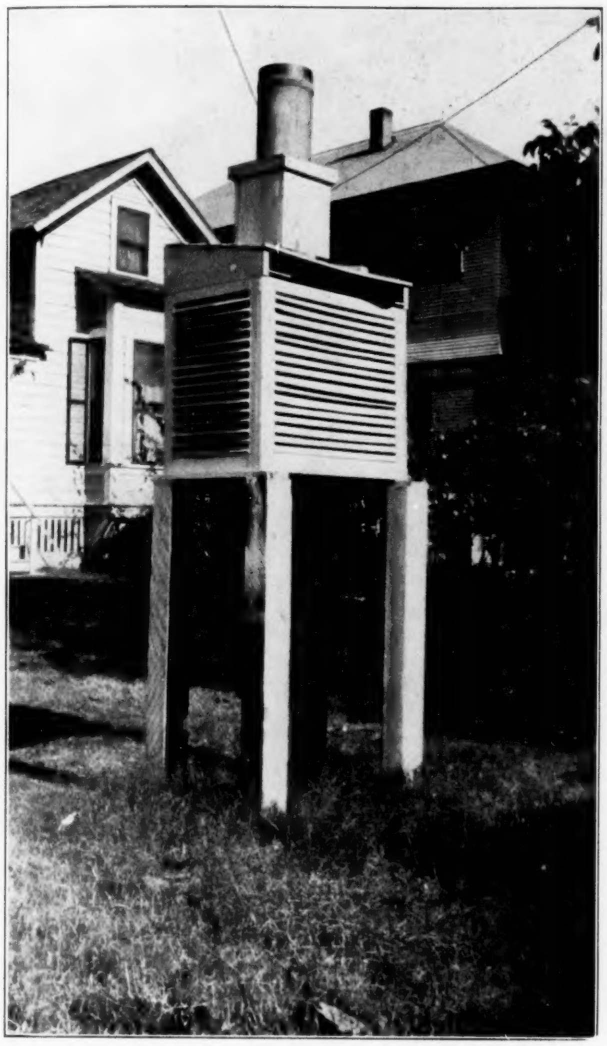


FIG. 19.—Thermometer exposure at San Bernardino, Cal. This shelter is located among a few orange trees in the back garden of Cooperative Observer Dr. A. K. Johnson. It will be noted that the rain gage is on the roof of the shelter "to prevent interference."
[This illustration is reproduced to show how the rain gage should *not* be exposed. The gage should be installed *on the ground* and all interference otherwise prevented.—C. F. M.]

FIG. 21.—Thermometer exposure at Riverside, Cal. The thermometer shelter and rain gage of the cooperative observer.
[This shows a proper exposure for the rain gage.—C. F. M.]

FIG. 20.—Thermometer exposure at Redlands, Cal. This shelter is in a marble-cutter's sales yard in the business portion of the city. It is across the street from the place of business of Cooperative Observer Hargraves, city editor of the "Redland Facts." [Figure omitted.]

FIG. 22.—Lemon picking, January, 1914, at Whittier, Cal. Lemons are picked throughout the year, as the trees are continually bearing. Size alone determines the conditions for picking. Special attention is drawn to the tips marked by asterisks (*). These show the effect of the high, drying winds of December, 1912. All the leaves were stripped from the shoots by the desiccating action of the "norther." The new growth will be seen to be rich and abundant. Mr. G. Harold Powell estimates that the drying winds that preceded the freeze of 1913 were responsible for probably 50 per cent of the damage to last season's citrus crop.

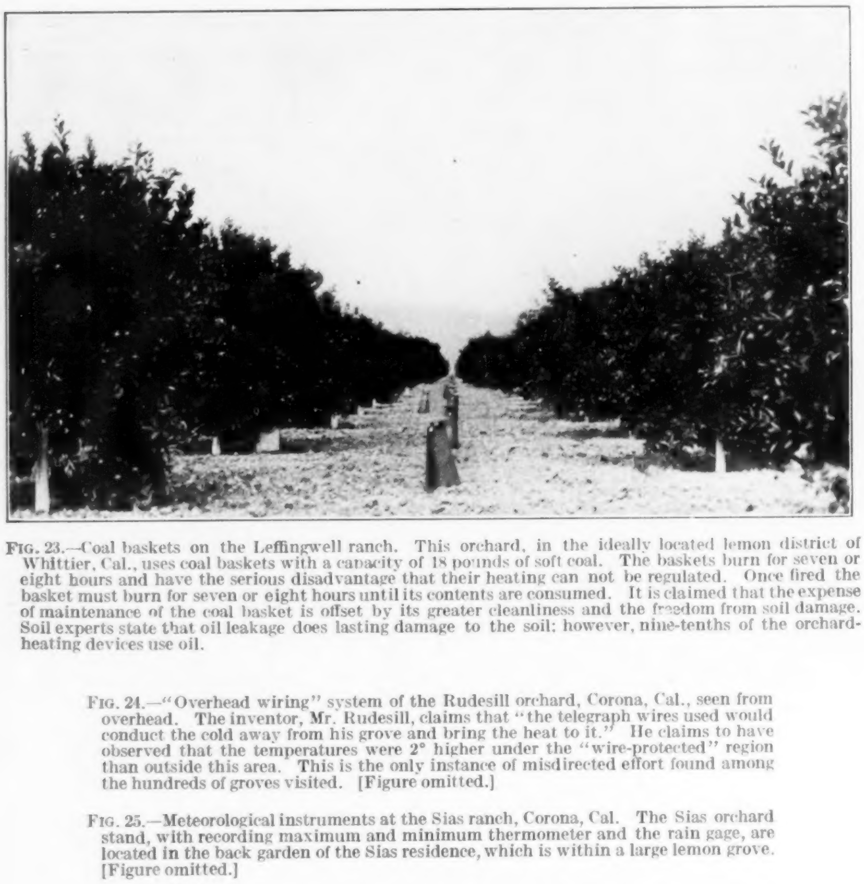


FIG. 23.—Coal baskets on the Leffingwell ranch. This orchard, in the ideally located lemon district of Whittier, Cal., uses coal baskets with a capacity of 18 pounds of soft coal. The baskets burn for seven or eight hours and have the serious disadvantage that their heating can not be regulated. Once fired the basket must burn for seven or eight hours until its contents are consumed. It is claimed that the expense of maintenance of the coal basket is offset by its greater cleanliness and the freedom from soil damage. Soil experts state that oil leakage does lasting damage to the soil; however, nine-tenths of the orchard-heating devices use oil.

FIG. 24.—"Overhead wiring" system of the Rudesill orchard, Corona, Cal., seen from overhead. The inventor, Mr. Rudesill, claims that "the telegraph wires used would conduct the cold away from his grove and bring the heat to it." He claims to have observed that the temperatures were 2° higher under the "wire-protected" region than outside this area. This is the only instance of misdirected effort found among the hundreds of groves visited. [Figure omitted.]

FIG. 25.—Meteorological instruments at the Sias ranch, Corona, Cal. The Sias orchard stand, with recording maximum and minimum thermometer and the rain gage, are located in the back garden of the Sias residence, which is within a large lemon grove. [Figure omitted.]

FIG. 26.—Natural drainage by an arroyo at Corona, Cal. The arroyo at the right drains a great portion of the Corona lemon district of cold air. Observations show an inversion of from 14° to 18°. Further experiments as to the change in temperature with wind direction and velocity and under varying moisture conditions will be carried on by Cooperative Observer J. E. Garthwaite. [Figure omitted.]

FIG. 27.—Orchard thermometers, recording minimum thermometer, alarm thermometer, and their supports. Garthwaite groves at Corona, Cal. [Photo by Garthwaite.]

W F 32 3. 28

Winter weather records. Night beginning.................. Lowest min........

	1	2	3	4	5	6	7	8	9	10	D. P.	R. H.	Wind.	Sky.	Remarks.
4															
5															
6															
7															
8															
9															
Min.															Temperatures taken in open 3 feet above ground.

FIG. 28.—Card for weather records; from the card system in use by the Corona Lemon Co. Designed by J. E. Garthwaite, manager. The abbreviations on the card have the following meanings: W=Watchman (steel tag). F=Fired. A yellow tag indicates a Weather Bureau warning received at the time it gives. A white tag on the figures 28, 30, or 32 indicates the temperature. Vertical columns headed 1, 2, 3, etc., indicate hours. Horizontal lines numbered 4, 5, 6, etc., indicate the sections of the protected region to which the entries apply.

Watchman's report.

Night of.........., 191... Watchman................................

Time.	Temperature. Station 1.	2.	3.	4.	5.	6.	Alarm.	Help called.	Weather changes (mark time of appearance of frost, dew, cloud, wind, or wind changes, fog, rain).	Pots lighted (give number of pots lighted or extinguished at any time; give damper changes).
5										
30										
6										
30										
7										
30										
8										
30										
9										
30										
10										
30										
11										
30										
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2										
30										
3										
30										
4										
30										
5										
30										
6										
30										
7										
30										
8										
Min.							Remarks:			

Make all marks at nearest half hour.

FIG. 29.—Watchman's report blank, in the warning system used by the Corona Protective League, J. E. Garthwaite, manager.

FIG. 30.—Testing orchard thermometers. A dozen orchard recording minimum thermometers and stands in process of hourly tests during a cloudy day. It was pointed out to the designer, Mr. Garthwaite, that he had made no provision for the accumulation of dew or moisture on the thermometer bulbs which would naturally give him erroneous readings even with a light wind blowing. It was suggested that this fault could be remedied by attaching a simple shade over the thermometer. [Figure omitted.]

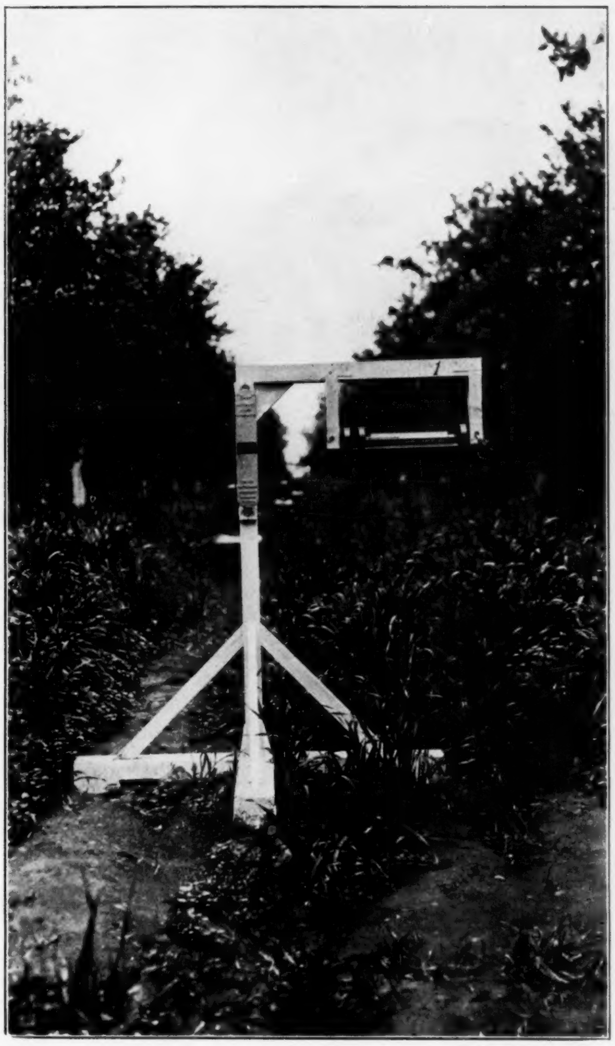

Fig. 31A.—Alarm thermometer and mounting in orchard at Corona, Cal. This alarm thermometer is one of the closed-circuit variety. A drop to critical temperatures breaks the circuit, opens a relay and operates an alarm in the watchman's quarters. The photograph also shows the rank growth of the "cover crop" carefully cultivated in the lemon groves. When this growth attains its maximum height it is plowed under; thus humus material is supplied to the soil. [Fig. 31B, omitted.]

FIG. 32.—Approved oil pots as they are distributed in the Corona groves. The oil pots are shown with the tops removed, thus the lighting and filling devices are visible. Each pot in this district is seated on a concrete slab, regularly inspected for rust spots, and varnished often. The average smudging period in Corona for lemons is December 10 to March 10. During the past season (1913-14) oil pots were lighted on 27 nights.

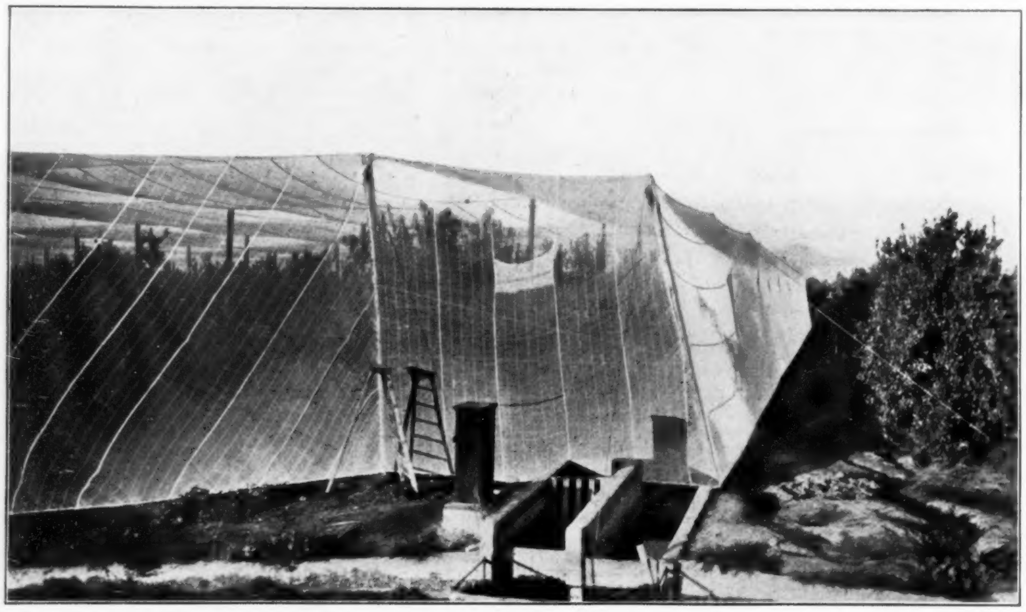

FIG. 33.—A 5-acre lemon orchard under cloth, Corona, Cal. Experienced lemon growers think that while this method might be a great advantage in protecting against scarring by high winds (if the latter do not destroy the covering fabric), yet the expense of $200 per acre would not justify its use for checking radiation. During one week the daily minimum under the covering averaged 4° F. higher than the outside minimum. (See fig. 17.)

safely. Protection by oil pots is an expensive undertaking, the cost of equipment per acre being in excess of $180, with $33 for maintenance and deterioration. Cost of labor and oil would be additional. Coal baskets are favored by an inconsiderable number of orchardists. There is one feature in their favor, and this is that there is no oil leakage in the grove. Oil drippings in the groves are detrimental to the trees, so that great care has to be exercised to prevent such damage. The piping of fuel oil and the use of burners is thought to be impracticable for the reason that it is difficult to obtain a good pipe joint, and the leakage then being so near the roots would injure the trees. Various systems of covering the groves have been tried, cloth in Pomona (fig. 17) and Corona (fig. 33), lath at San Fernando (fig. 12), and glass at Fillmore (note on fig. 8). The only available thermograph records as to temperatures within and without an orchard covering have been made by Cooperative Observer J. E. Adamson, of Pomona. Traces of thermograms are reproduced in figure 17. It was found that the minimum temperature within the inclosed portion of the grove was from 2° to 8° higher than the outside minimum, and that during warm days the minimum within the inclosure was also from 3° to 4° warmer than outside. The experiments have not proved satisfactory to those who have conducted them. The experimenters feel that some sort of covering is desirable to protect from the drying winds as well as from the cold, but the ideal shelter is yet to be constructed. In this, and in all other lines, intelligence of a high order has been brought to bear on the many problems constantly confronting the citrus orchardist. For example, elaborate thermometer tests are carried out in scores of orchards (fig. 30), air-drainage observations are being made (fig. 26), and only once during his visits did the writer find an instance of misdirected effort (fig. 24).

(*i*) *Necessity of closer relations between orchardists and the Weather Bureau.*—The orchardists appreciate the aid given them by the Weather Bureau. Being intelligent men, they realize the limitations of the endeavors made to serve them. They do not ask the impossible. In closing this report it is suggested that efforts be continued along the lines of more specific forecasts, including in the frost warning more than the mere statement that frost is expected. It is desired that, when possible, probable relative humidity values be included, as well as other pertinent information. Forecasts as to the drying winds of late autumn, winter, and early spring (fig. 22) would also be valuable as additional protection and in planning irrigation.

In conclusion it may be stated that there is a unanimous desire for closer relationship, leading to helpful cooperation, between the orchardists and the bureau.

III.

LETTER ON FROST AND FROST PREVENTION.

By J. W. GARTHWAITE, Manager.

[Dated Corona, Cal., Feb. 4, 1914.]

I have been through Prof. Humphreys's very interesting paper [see above, p. 562] with great care and feel that from a general point of view he has covered the subject extremely well. From the standpoint of the citrus grower I may offer a few suggestions.

We have all had a general understanding that, as Prof. Humphreys says, the temperature of the air a few feet above the ground will be found a good deal higher than that at the surface. The results of the freezes of December, 1911, and January, 1913, were such as to indicate that, in this section at least, damage was general in all parts of the trees; in some cases seeming to have been more severe at the top. This condition could be accounted for by the fact that there is often more tender growth at the top than in other parts of the tree. Of course in many orchards all the fruit was frozen, regardless of location; but in such as were more fortunate the good fruit was not to be found more on the higher branches than on the lower, but rather where the particular piece of fruit was protected by a covering leaf or branch. However, these two freezes are probably not to be taken as typical, since they did more damage to high ground than low; but as they are the only freezes that have done serious damage in this section they are the only ones that I can cite.

The well-recognized frost indications of which he speaks do not seem to be reliable in this district. For instance, a low temperature at 8 p. m. is very often a false alarm, while a high thermometer at the same time in the evening is often followed by frost. A clear sky is, of course, a bad sign; also a few times this winter I have retired feeling that all was lovely because of clouds or even a dense fog, only to be awakened at some cruel and unusual hour by the frost alarm to find clouds or fog gone the way of all flesh. And the same thing applies to wind. At no time this winter have I observed a dew point below 36°F., and yet on 19 nights the temperature has dropped to 32°F., or lower. On December 28, 1913, the dew point at 5 p. m. was 48°; at 6 p. m. it was 46°; at 8 p. m., with the temperature at 40°F., I found dew forming; at 10 p. m., with the temperature at 42°F., I found that the dew had disappeared and the dew point was 41°; at 3 a. m. dew began again to form at 33°; the minimum was 30°F. This is a fair sample of the way the humidity behaves in this benighted region. These facts probably account for the very frequent finding of frozen dew here.

The keeping of the ground clear and rolled, as suggested, is not practical in most citrus districts, owing to the necessity of growing humus crops and that of winter irrigation during seasons of insufficient rain.

Prof. Humphreys suggests the possibility of building a wall or growing a close hedge to prevent the setting in of cold air, and this calls to mind the fact that last winter many orchards were saved by eucalyptus wind-breaks on the north side. This was due, no doubt, to the fact that a great deal of the damage was done by a cold heavy gale from the north.

The objection that spraying trees with water would injure the bloom by washing away the pollen would not seem to be a consideration in the case of citrus trees; no damage ever having been noted after spraying, with all kinds of chemicals, during the blooming season even under pressure of from 175 to 200 pounds and perhaps higher. Such spraying is practiced about San Diego at all times of the year. And was reported by the writer last spring for the control of red spider.

Under the head of irrigation there are one or two points which it might be well to consider. In the central part of the State, and probably in other parts as well, a great many growers seem to have all the water they need from deep wells, which on a frosty night would be considered quite warm. This water would seem to be available at all times and so might be useful. In general, however, there is no doubt that Prof. Humphreys is right in objecting to this means of preventing frost. However,

it would be particularly bad where used as a help to the usual firing method, as it might make the ground so soft as to render refilling of the pots a very difficult operation. In the case, too, of most of the growers in southern California the water supply would be too uncertain, as here we irrigate for only a couple of days in each month and the stream is then passed on to the next ranch; in seasons when there is rain enough to warrant it the water is shut off completely during the winter months—as it is now [in February] in this district.

Above all, it would seem that in a paper on frost prevention the reader should be constantly warned to be ready—or, better yet, to be ready for frost at any time. Every one should be made to understand that conditions change in a very short time and that a fine springlike day may be followed by a cold night. No one should wait for warnings or indications, but, whatever his means of protection, he should be prepared to put them in operation at any hour during any night in the cold season.

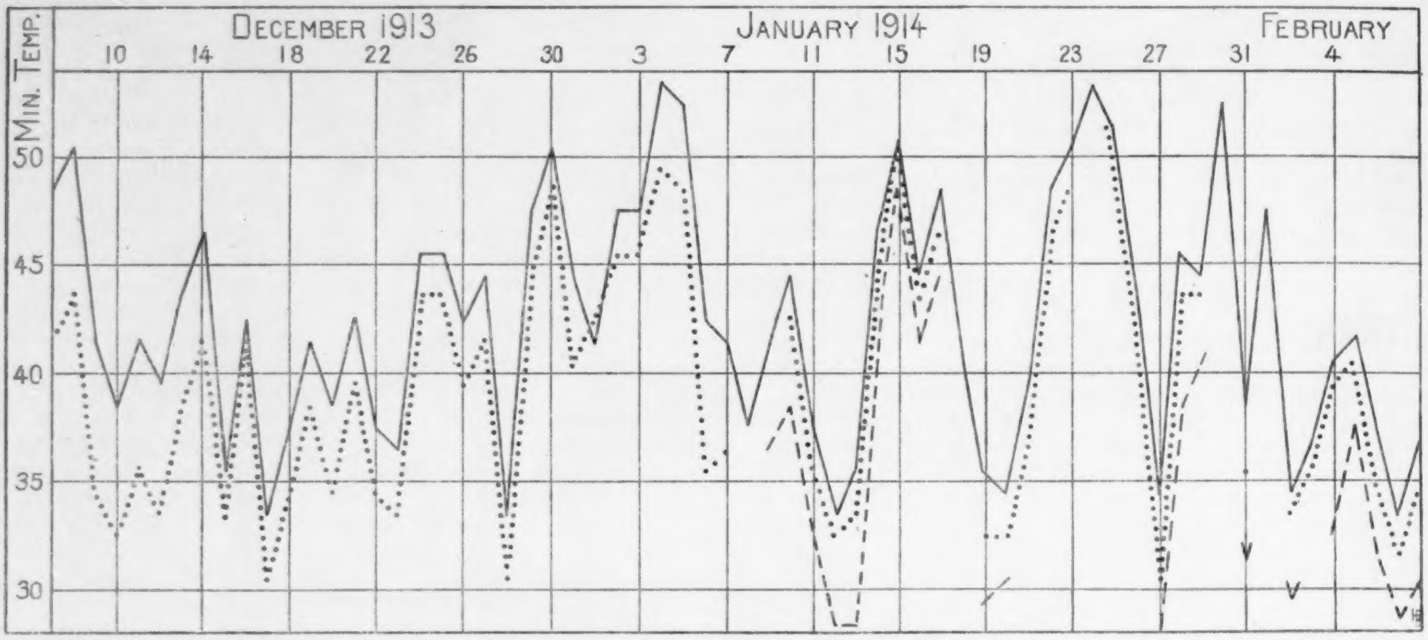

FIG. 1.—Diagram showing comparative temperatures in December, January, and February, 1913-14, at the Garthwaite ranch, Corona, Cal. (By J. W. Garthwaite, cooperative observer, Mar. 22, 1914.)
———— Thermograph record in shelter. . . . . . Minimum thermometer readings in open, near shelter. - - - - - Minimum thermometer readings in the open, 100 feet from the shelter and at the bottom of an arroyo 14 feet deep.

IV.

MEMORANDUM ON AIR DRAINAGE IN THE VICINITY OF THE CORONA DISTRICT, CAL.

By FORD A. CARPENTER and J. W. GARTHWAITE.

[Dated Los Angeles, Mar. 23, 1914.]

The general effect of air drainage is noticed in the distribution of local winds during "norther" conditions. The north wind, by reason of the topography, assumes a northeasterly and later a southeasterly direction. It is locally called a "Santa Ana" for the reason that the wind is blowing down the valley (fig. 2) of the Santa Ana River. As an accompanying view (fig. 3, p. 570) shows, the first effect of the wind is shown by the formation of the dust cloud far in advance of the wind; as the wind becomes stronger and the disturbed air of greater vertical thickness, the cloud becomes general and obliterates everything. In passing, I would observe that the dry desiccating winds of the season of 1912-13 greatly damaged the citrus crop. This wind is strong and steady and apparently free from swirls or squalls.

The local effect of air drainage will be seen in the

FIG. 2.—Sketch by Garthwaite, showing the topography in the vicinity of his ranch at Corona, Cal. Mount Wilson is north of Corona. Contour interval, 1,000 feet; * the arroyo mentioned in figure 1; ‡ Garthwaite ranch.

profile (fig. 1) of minimum temperature thermometers

in a standard shelter at the station, the thermometer in the open, and the thermometer in a shelter at the bottom of a neighboring arroyo (dry river bed) 14 feet below the station. The humidity that prevails during the continuance of a "norther" is shown by the chart of March 16, and the curve of observed humidity is shown by the hygrogram of March 16–20, 1914. Mr. Garthwaite tells me that he has observed the varying currents of wind in the early morning, when smudge fires were first started, to follow the contours in a most accurate way. He is constructing a delicate wind register so as to show the relative direction and force of the wind in the arroyo and at his station. If it were feasible, it might seem advisable to furnish the cooperative observer two anemometers and a register on which would be recorded both the station and the arroyo winds. Another thermograph for use in the arroyo would also give interesting and instructive results.

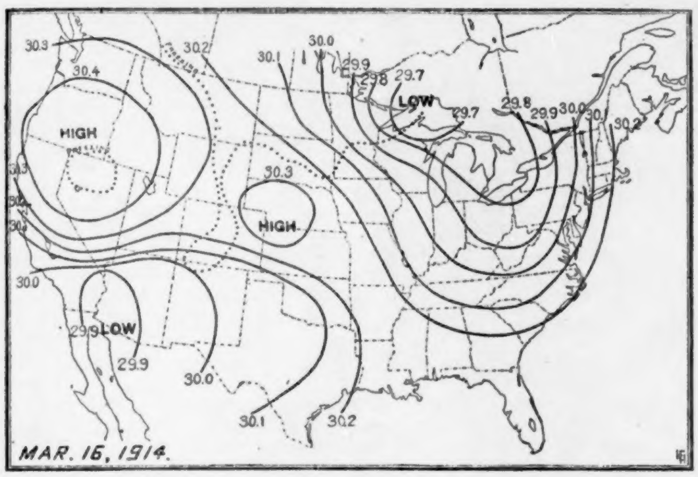

FIG. 4.—

LOS ANGELES, CAL., MONDAY, MAR. 16, 1914.

FORECAST TILL 5 P. M. TUESDAY.

For Los Angeles and vicinity: Fair to-night and Tuesday. Moderate northerly to north easterly winds.
For California, south of the Tehachipi: Fair to-night and Tuesday.

WEATHER CONDITIONS.

The barometric pressure continues high from Oregon and Washington southeasterly to Florida, and fair weather and moderate temperatures prevail throughout the greater portion of the United States. A moderate southwesterly gale is in progress at Buffalo.
We are entering on the fourth consecutive week without storms on the Pacific slope. The barometer remains high in the Northwest and moderately low in the valley of the Colorado. This considerable difference in pressure conditions will bring about marked "norther" weather during the ensuing 36 hours. Warning of moderate to strong northerly and northeasterly winds was sent by wireless to Avalon this morning at 6:30. The weather will continue fair and dry in Los Angeles and vicinity to-night and Tuesday, with moderate northerly and northeasterly winds.

Special California reports.

Orchard readings.

Stations.	Weather.	Temperature.		Precipitation.	
		Highest yesterday.	Lowest last night.	Daily.	Seasonal to date.
Pasadena	Clear	83	50	0.00	31.77
Pomona	Clear	77	43	.00	25.56
Redlands	Clear	82	50	.00	15.59
Riverside	Clear	79	48	.00	12.51
San Bernardino	Clear	83	45	.00	17.20
Santa Barbara	Clear	68	46	.00	29.58

FORD A. CARPENTER, *Local Forecaster.*

[NOTE BY F. A. C.]

Fishing fleet obeyed warnings and were safely anchored hours before the "norther" began to blow.

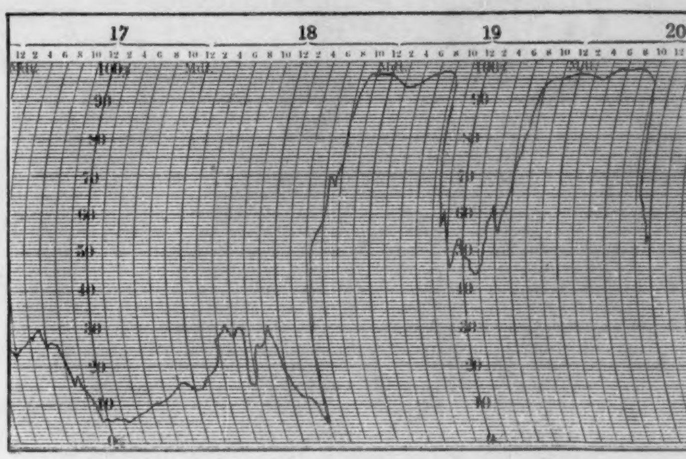

FIG. 5.—Hygrogram at Claremont, Pomona, Cal., March 16–20, 1914. "Norther" humidity conditions are shown by the above record for the 17th and 18th, while the normal curve is shown on the 19th and 20th. The hygrograph was in excellent condition and tested at the beginning of the month; the records may be relied on to within 4 or 6 per cent. At 4 p. m. of the 18th the relative humidity was 5 per cent, but within four hours the humidity rose to 97 per cent as the effect of the cessation of "norther" conditions.

V.

FROST WARNINGS AND ORCHARD HEATING IN OHIO.

By J. WARREN SMITH, Professor of Meteorology.

[Dated Weather Bureau, Columbus, Ohio, Nov. 4, 1914.]

(*a*) Introduction; (*b*) Orchard heating in 1913; (*c*) Fruit-frost stations in 1914; (*d*) Frost warnings issued, 1914; (*e*) The results of orchard heating in 1914; (*f*) Different methods of heating orchards; (*g*) Oil heaters; (*h*) Coal heaters; (*i*) Wood fires; (*k*) Temperatures dangerous to fruit buds; (*l*) When to expect frost; (*m*) Dates of blossoming of fruits; (*n*) Predictions of frost and minimum temperature; (*o*) Frost conditions vary; (*p*) Differences in minimum temperatures; (*q*) Daily range in temperature; (*r*) Predicting minimum temperatures from dew point; (*s*) Diurnal temperature changes; (*t*) Typical thermograph curves, May 11–18, 1914; (*u*) Predicting minimum temperatures from median; (*v*) Rules for predicting minimum from median temperature; (*w*) Suggestions to fruit growers in predicting minimum temperatures from the median; (*x*) Instruments to be used; (*y*) Prospective extension of this service.

(*a*) *Introduction.*—For a number of years the writer has been urging the practicability in Ohio of protecting orchard and garden crops from frost damage by smudging and heating. Within the past few years quite a number of the most progressive fruit growers of the State have taken up the matter of frost protection in a serious manner.

Warnings of general frosts have been widely distributed by telegraph and telephone, but it has seemed desirable to give more specific information as to the probable severity of the frost and the probable minimum temperature in the orchards or sections of the State where orchard heating has been taken up.

Therefore, in 1912, we began the organization of a special fruit-frost service in Ohio and in the spring of 1913 had special stations in complete operation at Delaware and Toboso, and in partial operation at a few other points.

It was estimated that the special warning service and the work of orchard heating about Delaware, Ohio, saved the fruit growers in that vicinity some $35,000 or $40,000 during the severe freeze in May, 1913.

(*b*) *Orchard heating in 1913.*—In Table 1 the result of some of the orchard heating as done in 1913 and in a few previous years is given. The notes following the table give additional information as to heaters used, fuel, mistakes in having insufficient fuel, discouragements, etc.

TABLE 1.—*A summary of experiences in orchard heating in Ohio.*

Place and county.	ear.	A	Kind of fruit.[1]	Fuel used.	Number of fires per acre.	Temperature outside orchard.	Temperature within orchard.	Enough fires?
						°F.	°F.	
Ashville, Pickaway	1910	27	Ap.; ph.; pr.; pm.; ch.	Stove wood	50	30	38	Yes.
Bellefontaine, Logan	1913	5	Ap.; ph.; pr.; ch.	Logs, brush	4	28	34	No.
Bellevue, Huron[2]	1913	80	Ch	3 gals. oil	35	22	30-32	Yes.
Cadiz, Harrison	1913	30	Ap.; ph.; pr	Coal slack	5	20	......	No.
Celina, Mercer	1913	6	Ap	Wood trash	3	23	......	No.
Cheshire, Gallia	1913	....	Tm	2 gals. oil	25	26	38	......
Chillicothe (1), Ross	......	225	Ap.; ph.; sm	3 gals. oil	50	30	36	Yes.
Chillicothe (2), Ross	......	20	Ap.; ph	Brush sawdust.	......	......	......	No.
Clyde, Sandusky	1913	10	A	1½ gals. oil	75	22	27	No.
Delaware (1), Delaware.	1913	45	Ap	3 gals. oil	30	23	30	No.
Delaware (2), Delaware.	1913	40	Ap	.....do	35	23	30-32	Yes.
Dellroy, Carroll	1913	6	Ap	Coal, wood	......	24	33	......
Frankfort, Ross	1913	20	Ap	Wood	......	28	......	......
Freeport, Harrison	1910-1911	33	Ap	Coal, 6 qts. oil.	60-80	26	34	Yes.
Glouster, Athens	......	......	......	Coal, oil	......	......	......	......
Marion, Marion	1913	7	Pr.; pm.; ch	7 qts. oil	135	26	30-32	Yes.
Shelby, Richland	1913	14	Ap	See rmks	4-8	......	......	No.
Toboso, Licking	1912	....	Ch.; str	Oil pots	30-50	29	36	Yes.
Wakefield, Pike	1913	95	Ph	8 gals. oil	75	26	32	Yes.
Waterville, Lucas	1913	125	A	3 gals. oil	40	28	33	Yes.
Wooster, Wayne	1913	10	Ap.; ph	.....do	120	21	27-30	Yes.

[1] Contractions.—A., all kinds; ap., apples; ch., cherries; ph., peach; pr., pear; pm., plum; sm., small fruit; str., strawberries; tm., tomatoes.
[2] Mail address, but the orchard is in Sandusky County.

Remarks from stations in Table No. 1.

Ashville.—"In 1910 I saved 75 per cent of my crop by means of the fire. When the temperature fell to 34° I would begin and light every other fire, and then if the temperature kept on falling lower I would light every pile of wood."

Bellefontaine.—"I saved 400 bushels of fruit, but should have saved 1,600 more; had four cold nights and ran short of fuel. Have ordered 3-gallon Hamilton heaters for use another year."

Bellevue.—"Gathered 99 tons of cherries; would probably have had from $5,000 to $7,000 worth more if we had had a larger number of heaters. It took six men 2 hours to light 2,200 stoves."

Cadiz.—"I saved about one-fourth of the crop. The coal was in 5-bushel piles."

Celina.—"I am a firm believer in the heating business as I have used it for over 20 years and have gotten good results from it. This year I did not have fires enough to the acre and no fruit worth speaking of was saved."

Cheshire.—"On the night of October 21, 1913, we tried the oil heaters in the tomato field and raised the temperature from 26 to 38 degrees with 25 heaters burning, Later in the night we began to have some trouble and the temperature fell to such an extent that we were unable to raise it in time to keep the tomatoes from freezing. I think the oil heaters are all right when cheap oil can be secured; for southern Ohio I think the coal heaters would be better. One of my neighbors used two coal smudges for his garden and they were a success. On the night of October 13 with 25 smudge fires burning on 1 acre we raised the temperature 5°."

Chillicothe, No. 2.—"I have succeeded in years past with fires in orchards on calm frosty nights, but failed in April of this year because of the very high wind that accompanied the cold weather. I hope to use heaters hereafter."

Clyde.—"There were not enough heaters to the acre of the size used. There has scarcely been a proper test of oil orchard heating around here; as we have either run out of oil or have not for some reason used heaters every night when we should have. This year I ran the heaters from about 10 p. m. till morning during the very cold spell about three weeks before May 10; and May 10, when we should have by all means had oil and run the heaters, we had none here. My heaters are too small to burn all night."

Delaware, No. 1.—"Thirty fires to the acre was not enough this year; there should be at least 50. On the upland the temperature was about 30° where the heaters were used. On the black land it was considerably lower than that. I was a little late in lighting my heaters. I should have begun at least one hour earlier. If I had twice as many heaters I would have saved fully $10,000 worth of apples. Some of the trees in this orchard showed a good crop on the side of the tree where the heater stood and practically no fruit on the opposite side."

Delaware, No. 2.—"I saved fully 8,000 bushels of apples by the use of the orchard heaters."

Dellroy.—"I did not use heaters, but built fires of old rails and coal and find that where I had about three small fires for each tree I saved most of the fruit, but where I had but one fire in the square of four trees I lost all of it even though the fires were large. I fired four nights and the consequence was the last night, which was the worst of all, I fell short of fuel just when I needed it most. I did not heat all of the orchard, but saved 200 bushels, and would not have had any except for the heating. I expect to put 1,000 bushels of coal in the orchard this winter and 100 loads of wood and have plenty of fuel and do the thing right next time."

Frankfort.—"We used small wood fires in every other row in the orchard. We saved possibly 2,000 bushels of fruit. In this same orchard heaters were used in the fall at picking time. The temperature was falling rapidly and reached about 22° outside the orchard, but by burning the fires between the rows the temperature was kept up to about 28°."

Freeport.—"Three years ago I used the fire pots with great success, and they saved the crop. This year my men were rather unprepared, there was a great gale, they could not get help, got a bad start, had the blues, did not put out their thermometers, selected only the most desirable places and trees, but undoubtedly saved enough apples to make about half a crop. In 1910 we saved 2,000 barrels and in 1913, 1,000 barrels. In 1911 I saved about 2,000 barrels on 8 acres."

Glouster.—"I used crude oil, shavings, and coal last year, which made a good fire, and I probably saved the apples. This year I had coal distributed over the orchard, but could not get the help to properly fire it, so I have given up the idea of coal. I expect to get oil heaters next year to use crude oil in as I have the oil and think it most practicable."

Marion.—"I did not fire early enough this year to save the crop. I waited until the temperature was down to 26°, which is too low. It should be fired when the temperature is not lower than 30°."

Shelby.—"We can control an ordinary frost with saltpeter, sawdust, corncobs, and coal oil by making a smoke, but in this instance water froze in the early part of May from one-fourth to one-half inch. We take corncobs and dip them in a solution of wood alcohol and saltpeter. We use about two or three of these cobs, ignite and set in sawdust, more or less damp, impregnated with coal oil and saltpeter. One pint of coal oil, one ounce of saltpeter put into a kettle of sawdust will burn and permeate a wonderful amount of smoke for 12 to 24 hours. We used four to eight kettles per acre. We aim to have lanterns made with large hoods to spread the heat and put in the center of each apple tree during freezing weather."

Toboso.—"At this place they have positively demonstrated the practical value of orchard heaters in small fruit. In 1911 they lost 70 per cent of the cherries and all of the strawberries that were outside of the firing area and saved all within. They lighted 30 to 50 pots to the acre and raised the temperature 7° when outside the area it fell to 29°. In 1912 they saved 10 acres of strawberries yielding 5,000 quarts per acre."

Waterville.—"I do not think I saved any fruit by the use of the heaters."

Wakefield.—"We saved about two-thirds of a crop, or about 8,000 bushels of peaches. Did not heat one night when we should have done so."

Wooster.—"We saved about one-half bushel per oil pot. It was necessary to fire five nights and we had unusually severe conditions this year. We light the pots on low ground when the temperature falls to 30° and gives reason to believe that it will go lower, and try to keep it above 28°."

(c) *Fruit-frost stations in 1914.*—After the experience in 1913 there seemed no question as to the value of orchard heating in this State. Believing also that special reports from different sections of the State were an aid in predicting minimum temperatures the following-named stations were set in operation in the spring of 1914.

TABLE 2.—*Special fruit-frost stations, 1914.*

Station.	County.	Observer.
Clyde	Sandusky	Mrs. Ella P. Heffner.
Delaware	Delaware	DeWitt H. Leas.
Germantown	Montgomery	Henry M. Wachter.
Green Hill	Columbiana	Joseph E. Bentley.
Haydenville	Hocking	H. W. Stiers.
Jackson	Jackson	David F. Jones.
Marietta	Washington	Charles K. Wells.
Mount Healthy	Hamilton	Victor Herron.
Toboso	Licking	H. A. Albyn.
Wooster	Wayne	Paul Thayer.
Worthington	Franklin	Frame C. Brown.

Maximum and minimum thermometers, a raingage, and a sling psychrometer were furnished these points, and at Delaware, Toboso, Wooster, and Worthington self-recording thermometers were put into operation.

Daily observations of the highest and lowest temperature, dew point, state of weather, wind direction and approximate velocity, and rainfall were regularly made at 6 p. m. during March, April, and May. Daily mail reports were sent from all of these points and daily telegraphic reports from most of them immediately after the observation was taken.

The location of these special fruit-frost stations is shown on chart 1 (fig. 12) as well as the location of some of the orchards where frost protection is being carried on in some form.

Figure 1 [omitted] shows the thermometer shelter and instruments at the special station at Delaware, Ohio. These instruments are located in the open back yard of the residence of the observer on West Winter Street. It is a rather open residence district and the exposure of the instruments is very similar to an exposure in an orchard.

The shelter faces north. The maximum and minimum thermometers and thermograph are shown within the shelter and the sling psychrometer hangs on the outside of the shelter beside the door. At the right side within the shelter there is a tipping-bucket raingage, made by the observer. The receiver is seen projecting above the top of the shelter. The official raingage sets on the ground just outside the picture in an open yard, with the top about 3 feet above the surface of the ground.

Individual orchardists who carry on orchard heating provide themselves with reliable thermometers and make daily card reports to the Columbus office to determine the difference between their orchard temperatures and those at the nearest special station.

(*d*) *Frost warnings issued.*—During the spring of 1914 frost warnings for Ohio were issued as usual in connection with the general forecasts, at about 9 a. m. In addition to this the Columbus office arranged to telephone certain fruit centers at about 9 o'clock in the evening, giving our estimate of the probable minimum temperature during the coming night. This was done only when frost conditions threatened and to aid the orchardists to determine whether to carry out plans for heating and what temperature they must fight against.

This special telephone service is furnished to the places shown in Table 3, as also to Marion and Gallipolis. The men telephoned to then further distributed the information to surrounding fruit and truck men. For example, the observer at Delaware passed the special forecast on to 10 different men, all of whom were prepared for heating. At Gallipolis arrangements were completed to have 18 different fruit men telephoned immediately upon receipt of the special forecast.

These special warnings were issued widely on the nights of April 19, 20, and 30, and on May 1, 2, 14, 15, and 16. In Table 3 there is given the temperatures predicted and the temperatures recorded the next morning as reported by orchardists in the vicinity. It will be seen that the predictions were too low for the first two nights, but improved steadily with study as the season advanced.

(*e*) *The results of orchard heating in 1914.*—In Table 4 there has been condensed something of the results of orchard heating in the spring of 1914. This will show that general heating was done on April 30 and May 1 and 15, and to a slight extent on May 2.

It is not possible to determine just what saving resulted from orchard heating this year. In a good many cases it is evident that the temperature would not have gone low enough to cause serious damage if no fires had been lighted. On the other hand, Mr. Koeppel of Delaware reported a severe loss to pears and apples on the night of May 15 because he did not have heaters enough to cover the orchard. In other cases strawberries were damaged and there is good evidence that fruit was damaged and dropped worse because of the cold weather than would have been the case if protected by heating.

Messrs. Pickett and Heffner of Clyde state that it is quite a question whether the waste and expense in years when heating is not necessary added to the expense when it is necessary does not make the cost too great to make heating profitable.

TABLE 3.—*Temperatures predicted and recorded, 1914.*

Stations.	Apr. 19.		Apr. 20.		Apr. 30.		May 1.		May 2.		May 14.		May 15.		May 16.	
	Predicted.	Recorded.	Predicted.	Recorded.	Predicted.	Recorded.	Predicted.	Recorded.	Predicted.	Recorded.	Predicted.	Recorded.	Predicted.	Recorded.	Predicted.	Recorded.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.		°F.	°F.	°F.	°F.	°F.	°F.	°F.
Clyde	25-28	34	25-28	34	27-28	33	30-32	35	Not so low	40	38-40	42	32-34	38	40	45
Columbus	30	36	30-32	35	29-30	32	29-30	30	do	46	....	....	35-38	31	....	34
Delaware	28-30	34	26-28	30	29-30	27-30	29-30	27-30	do	32	35	36	32	29-32	36	36
Green Hill	28-30	34	26-28	34	28-29	28	28-29	29	do	30	35-36	33	28-30	29	31-32	33
Haydenville	30	39	30	36	30-32	29	28-30	29	do	33	....	33	32	30	34-36	34
Jackson	30-32	41	28-30	36	30-32	33	30	36	do	39	38-40	38	33-35	35	36	38
Marietta	30-35	40	30-32	37	31-32	35	30	38	do	41	38-40	40	35	36	37	36
New Lexington	30	40	30	36	30-32	30	30	28-30	do	....	38-40	38	33-35	....	....	38
Toboso	28-30	36	26-28	35	27-28	28	27-28	29	do	35	35-36	35	30-31	29	35	....
Wooster	28-30	34	26-28	32	27-28	29	27-28	33	do	36	35-36	39	29-30	33	35-36	39
Worthington	28-30	35	28	....	28-29	30	28-29	29	do	38	32	....	31	30	35	....

Mr. Koeppel states that on some of the nights this year he had visitors from places distant 12 to 15 miles away who came to see the results of heating and who went home in the early morning satisfied of the practicability of the plan.

(*f*) *Different methods of heating orchards.*—Fires may be made of oil, coal, wood, or any other material that will burn readily. The majority of fruit men in Ohio use oil.

(*g*) *Oil heaters.*—There are some 10 or 15 different types of oil heaters on the market, varying from 1 to 6 gallons in capacity and costing from 15 cents to $1 or more. Figure 5 shows some of the kinds of oil heaters used.

The round heaters of the lard-pail type with the top about 7 inches across will burn at the rate of about 1 quart an hour. With 50 pots of the 1-gallon capacity burning per acre, 12½ gallons of oil will be consumed per hour.

TABLE 4.—*Results of orchard heating in Ohio on April 30–May 16, 1914.*

Location of orchard.	On high or low ground.	Condition of fruit buds. Apple.	Peach.	Cherry.	Pear.	Plum.	Kind of fuel.	Acres heated.	Number of fires to the acre.	Were there fires enough.	Hour when firing began.	Temperature when firing began.	Lowest temperature outside heated area.	Temperature where firing was effective.	Was fruit saved.	Name of orchardist.
NIGHT OF APRIL 30–MAY 1.												°F.	°F	°F.		
Barnesville	Both	Opening	Full bloom	Full bloom	Full bloom	Full bloom	Coal	$\frac{1}{2}$	36	Yes.	10 p. m.	34	29	38	Yes.	C. J. Eichhorn.
Bellefontaine	High	Showing pink	do	do	Nearly out		Wood and coal.		40	Yes.	Midnight	36	33	35	Yes.	J. L. Shawver.
Delaware	do	In bud	In bud	In bloom	In bloom	In bloom	Coal		100		do	37	33.5	38		J. B. Taggart.
Do	do	Nearly open		do	do	do	Crude oil	8		Yes.	9 p. m.	30	29			J. H. Miller.
Do	Both	Not open	Full bloom	do	do		do	23		Yes.	8 p. m.	32	28	40	Yes.	G. H. Koeppel.
Do	High	Opening		Not quite full bloom.	do		do				10:30 p. m.	34	30	35	Yes.	H. T. Main.
Do	do	Not open		do			do	1	30		9 p. m.			32		M. H. Main.
Do	Low	Showing pink		do		Full bloom	do	3		Yes.	9:30 p. m.	29	27		Yes.	R. L. Hudson.
New Lexington	do	Full bloom					Wood	$\frac{1}{4}$	22	Yes.	1:30 a. m.	33	30	34	Yes.	C. E. Pace.
Do	High	Opening	Full bloom	Full bloom	Full bloom	Full bloom	Coal	6	25	Yes.	1 a. m.	34	30	35	Yes.	J. W. Riley & Son.
Toboso	Both	Half open	Petals falling.	do		do	Crude oil	60	40	Yes.	3 a. m.	31	28	33	Yes.	H. A. Albyn.
Worthington	do	Showing pink	Full bloom	do	Full bloom	Blooming	do	50	40	Yes.	11:45 p. m.	32	30	36	Yes.	F. C. Brown.
Wooster	High		In bloom	do		In bloom	do	2	50	Yes.	3 a. m.	32	29.5	35		Paul Thayer.
NIGHT OF MAY 1–2.																
Delaware	Both	Not open	Full bloom	Full bloom	Full bloom		Crude oil	23	80	Yes.	8 p. m.	34	27	40	Yes.	G. H. Koeppel.
Do	High	Opening		Not quite full bloom.	do		do				10:30 p. m.	35	29.5	35	Yes.	H. T. Main.
Do	Neither	One-half out		do	Almost full bloom.		do		20		11 p. m.	35	30			W. E. Main.
Do							do.	3			10:30 p. m.	32	27			R. L. Hudson.
Kent		About to open	In bloom	Nearly in bloom.	In bud		Coal and wood.	3	1$\frac{1}{2}$	Yes.	Midnight	32	26	33	Yes.	M. H. Heighton.
New Lexington	Low	Full bloom					Wood	$\frac{1}{4}$	22	Yes.	1:30 a. m.	33	30	34		C. E. Pace.
Do	High	Bursting	In bloom	In bloom	In bloom		Coal and wood.	6	25	Yes.	2 a. m.	34	28	34	Yes.	J. W. Riley & Son.
Toboso	Both	Half open	Falling	do	do	Full bloom	Crude oil	75	50	Yes.	3 a. m.	31	29	33	Yes.	H. A. Albyn.
NIGHT OF MAY 2–3.																
Delaware							Fuel oil						32			W. E. Main.
Do	Both	Not open	Full bloom	Full bloom	Full bloom		Oil	23	40	Yes.	11 p. m.	34	32	36	Yes.	G. H. Koeppel.
NIGHT OF MAY 15–16.																
Ashland	Rolling	Bloom off	Shedding shucks.	Shucks nearly off.	Forming fruit.		Wood	12	40	Yes.	1:30 a. m.	36	32	40	Yes.	L. H. Ward.
Barnesville	Both	Some done	do	do	Shucks off		Coal and wood.	1	32		12:15 a. m.	33	32	35		C. J. Eichhorn.
Camp Chase	Rolling	Bloom off	Shedding bloom.	Fruit set	Fruit set		do	1	12	Yes.	2 a. m.	34	31–32	34	Yes.	E. A. Brenneman.
Chillicothe	Low	Fruit size of peas.	Fruit size of peas.	Fruit size of peas.	Fruit size of peas.		Saw dust, cobs, and oil.	4	18–30		1:30 a. m.	38	32	36–40	Yes.	M. I. Shively.
Delaware	Rolling						Crude oil	38	40–60	Yes.	11:30 p. m.	35	29	38	Yes.	G. H. Koeppel
Do	Hill side	Petals dropping.		Nearly off	All off		Oil			Yes.	1 a. m.	34	32	35	Yes.	H. T. Main.
Dublin	High	Most petals off					Wood	20	10	Yes.	do	31			Yes.	J. J. Dunn.
Freeport	do	Bloom well off					Oil and coal.	30	100	Yes.	Midnight	34	28–31	36		O. P. Kinsey.
Lisbon	do	In bloom		Fruit formed	In bloom		Black oil	3	45		2 a. m.	32	30	33	Yes.	C. W. Armstrong.
Toboso	Both	All off	Fruit size of peas.	Fruit size of peas.			Oil	50	60	Yes.	Midnight	33	29	32	Yes.	H. A. Albyn.
Worthington	Rolling	Fruit set	Fruit set	Fruit set	Fruit set		Fuel oil	20	40	Yes.	2:30 a. m.	30	30	35		F. C. Brown.

The fuel oil used should be of medium weight, as the light gravity oil burns too rapidly and is too expensive, and too heavy oil does not burn clean and a large amount of soot is deposited on the trees.

Oil heaters should be set at the rate of from 80 to 120 per acre. It is better to have too many heaters than too few. The fires should be thicker around the outside edge of the orchard and in low places. The temperature should be watched closely and when it has fallen nearly to the danger point every third or fourth heater should be lighted and then the others as needed. With heaters, where the burning surface can be controlled, the intensity of the fires can be varied as the temperature changes.

With an equipment of oil heaters having a capacity to go through the night without refilling, the general practice is to have 1 man for each 5 acres to take care of the fires.

The matter of lighting is interesting. Mr. Koeppel reports that on May 1 it took 4 men 3 hours to light the fires on 23 acres set at the rate of 80 to the acre. On the

14th, when they had 38 acres set at the rate of 40 to the acre on upland and 60 to the acre on lowland it took 5 men 3 hours to light the fires. On the 15th with the heaters the same as on the 14th it took 5 men 2 hours and 40 minutes.

Mr. Hudson at Delaware states that it took 3 men 1 hour to light 3 acres. At Lisbon they use black oil and 3 men lighted 140 fires in less than half an hour. Dr. Miller of Delaware used a wick fastened to wires for a torch and saturated it with oil. One man could light 100 fires in half an hour with this.

At Toboso on April 30 they had heaters set at the rate of 120 to the acre in the lowest part of their orchard. It took 4 men 1 hour to light one-third of these heaters on 60 acres. They use a torch that drops gasoline. At this place on May 1 they heated 75 acres with 50 pots to the acre and it took 5 men 1½ hours to light up.

The number of hours that the heaters will be burned will vary with each season, but if one stores 400 gallons of oil for each acre it will allow for burning one hundred 1-gallon pots per acre for 12 hours—sufficient for most seasons.

The initial investment for a 10-acre orchard, including tank, heaters, fuel for one season, etc., will be not far from $500, or $50 per acre. After the first year the cost will average $3 to $5 per acre for each night that heating is done. It is quite evident, however, that in a season like that of 1913 the saving resulting from the protection would cover the expense for a good many years.

(*h*) *Coal heaters.*—Coal heaters cost more than the oil burners, but it takes only about half as many per acre. The best coal burners hold 25 to 30 pounds of coal and will burn from 4 to 6 hours. It is considered that 1 ton of coal will equal 100 gallons of oil in heating value. At Barnesville, in 1914, with 36 coal fires to the acre, they kept the temperature 9° higher in the orchard than outside.

Oil-soaked waste and kindlings should be placed in the bottom of the coal heaters and then with a torch they may be lighted even faster than the oil heaters. The work of refilling will take about twice as much time as the oil heaters.

Mr. J. M. Stockham, of Portsmouth, has had success in making coal heaters from discarded cans used in making artificial ice. He cuts a 300-pound size can into three sections with a cold chisel. The lower section has holes punched through the sides for ventilation and is set on the ground. A cut is made near each of the corners, in the other sections, high enough to allow the sides to be turned under far enough to make a bottom that will hold wood and coal and yet allow for draft.

Each of these heaters will hold about 1 bushel of coal, so that for heating one night not more than one-third or one-fourth of a bushel should be put in. Mr. Stockham uses part coal and part wood. These discarded cans can be bought very cheaply, it is not a hard task to fix them as suggested, and they must be very durable.

Quite a number of men merely pile the coal on the ground between the rows of trees. In order to make the coal start to burning, Mr. H. W. Stiers, of Haydenville, has made a unique "kindler." He gets waste sticks about 1 inch square from a near-by planing mill and has them cut into 4-inch lengths. He then inserts these short pieces into a preparation of 1 part tallow to 10 parts rosin, and after sticking six of these pieces together he rolls them in fine shavings before they are quite dry. By pouring a small amount of oil on the kindlers they burn freely and ignite the pile of coal. The total cost of these kindlers to him is about one-third of a cent each.

By this plan the cost of heaters is saved, and where coal can be obtained as cheaply as it is in parts of Ohio it is recommended that the coal be given a thorough trial. It must be remembered, however, that there must be a good many piles of coal to the acre. Mr. Linard Rowland, of Cadiz, demonstrated in 1913 that five piles to the acre was insufficient.

(*i*) *Wood fires.*—Fires have been made of old rails, brush, and cordwood. In using cordwood the sticks are piled dovetailed together and are bushed together as the ends burn off. About six sticks of wood will last 4 or 5 hours. Wood needs more attention than either coal or oil and must be started earlier, as it takes some time to get the wood to burning enough to affect the temperature.

Mr. L. H. Ward, of Ashville, reports that it took 3 men 2 hours to light the wood fires on 12 acres at the rate of 40 fires to the acre. He used a few cobs soaked in coal oil at each fire. Mr. Pace, of New Lexington, states that it takes about 2 minutes to light each fire. His fuel was dry and burned readily. Some others found difficulty in getting the wood started.

The tables will show differences in temperature between the heated area and that outside with the different kinds of fuel, different number of fires to the acre, and under different temperature conditions. They show without question that a few fires to the acre will not prevent frost damage, but that with a large number of small fires the temperature can be kept above the danger point.

The reports of these fruit men show also that one must be thoroughly prepared in every respect. There must be plenty of fuel, men enough to keep the fires burning, and constant vigilance until the frost season is over. Care must be taken not to waste the fuel by lighting too early or on nights when the temperature does not fall to a dangerous point.

Thermometers should be distributed throughout the orchard and watched carefully, and when the temperature approaches the danger point the lighting should be begun in the coldest part of the orchard. Figure 6 shows some of the heaters in operation.

(*k*) *Temperatures dangerous to fruit buds.*—The hardiness of fruit buds varies with the season of the year, weather of the preceding days or weeks, the kind and variety of fruits, the condition of the tree during the preceding autumn, the position of the buds on the limb, etc. In general it is believed that the temperatures given below are safe temperatures if the cold is not of too long duration, but that damage would result if the temperature is below these values for any length of time.

PEACHES.

When the peach buds are showing pink, the dangerous temperature is about 20°F. When almost open, 25°; when newly opened, 26°; when petals are beginning to fall, 28°; when petals are all off, 30°; when the shucks or calyx tubes are beginning to fall—that is, just after the fruit is formed, 32°.

APPLES.

When the petals are beginning to show, 22°; when in full blossom, 29°; when the petals are dropping and the young fruit is increasing in size, 32°.

PEARS.

When just opening, 28°; in blossom, 29°; setting fruit, 30°.

CHERRIES AND PLUMS.

When just opening, 29° to 30°; when in blossom and setting fruit, about 31°. At Haydenville, in 1914, cherries were not injured, although the temperature fell to 28° while they were in full bloom. At Clyde, in 1913, the temperature reached below 25° while cherries were in bloom, and yet a fair crop was harvested, so that further investigations may develop the fact that cherries will stand a lower temperature than given above.

Fully dormant apple, pear, cherry, and plum buds will stand the usual winter temperatures that may be experienced in this State. Just how much cold a fully dormant peach bud will stand, it is difficult to determine. Some investigations made by the writer as to winter damage to peach buds in Fulton County, Ohio, covering a period of 30 years showed that few, if any, peaches were harvested whenever the temperature during the preceding winter fell to −17°F. Much depends upon the weather of the previous autumn and winter and the condition of the trees when they go into the winter.

The question of protecting peach buds from low winter temperatures by heating is receiving consideration in this State, and peach growers generally should try some experiments in this direction. There has been some difficulty in getting fuel oil to burn at low temperatures, but a lighter and better grade, as well as coal and wood, should be tried.

(*l*) *When to expect frost.*—Chart No. 2 (fig. 13) shows the average date of the last killing frost in the spring in Ohio and chart 3 (fig. 14) the average date of the first killing frost in the autumn. These date lines as they are drawn are only approximate because the dates depend so much upon the local topography. Locations in valleys always have later spring and earlier fall frosts than at near-by higher elevations.

The latest frost ever recorded in the spring is about four weeks later than the average date, at most stations. At stations in northern Ohio the earliest killing frost ever recorded has been about four weeks earlier than the average killing fall frost, and in the central and southern parts of the State the earliest killing frost has been about three weeks earlier than the average.

(*m*) *Dates of blossoming of fruits.*—Chart 4 (fig. 15) shows the average date of the blossoming of apples and chart 5 (fig. 16) the average date of the blossoming of peaches in Ohio.

In general, pears blossom a day or two earlier than apples, strawberries slightly earlier than apples, and cherries and plums slightly later than peaches.

By comparing charts 2, 4, and 5 it will be seen that the average date of the blossoming of fruit is earlier than the average date of the last killing frost in the spring. The frost season may be over before apples bloom in some seasons, but the other fruits are apt to be caught.

(*n*) *Predictions of frost and probable minimum temperature.*—The daily weather maps issued by the United States Weather Bureau show approaching areas of cool weather which may cause frosts, and when these conditions are anticipated the bureau issues general frost warnings.

Charts 6 to 8 (figs. 17 to 19) are typical frost maps and show the movement of the area of high pressure that caused the low temperature and frosts in Ohio the first of May, 1914.

On the map of April 30 there was much cloudy weather, and the indications were that it would continue cloudy with brisk northerly winds over Ohio that night with temperatures between 35° and 40°. The prediction was made, however, that if it should clear off frosts would occur.

The map of May 1 shows that while it did remain cloudy over much of the area it cleared in central and southeastern Ohio, and frosts resulted. It was very plain from that map that the high pressure area would be central over Ohio the next night, and thus the night would be clear with little wind and that general frosts would result.

The frost warnings are telegraphed and telephoned widely over the State, and every orchardist who plans to protect his crops by heating should take steps to obtain the warnings. The weather maps will be found to be of great help also.

(*o*) *Frost conditions vary.*—When the weather map indicates frost, and warnings are issued by the Weather Bureau, it is plain that the frost will be more severe in some sections of the State than others and that the temperature will be lower in the valleys and lowest parts of the farm during nights with clear and comparatively still air, when late spring and early fall frosts are most apt to occur. When the wind is blowing and the whole layer of air is below the freezing point then the hilltops suffer quite as much as the valleys.

The extremely low temperatures recorded in Ohio have been at the valley stations, because the lowest temperatures have come with clear, nearly still air. On the morning of February 10, 1899, the temperature was 21° below zero at Somerset, Perry County, while at Milligan, only a few miles away, it reached −39°F. Both stations have reliable thermometers well exposed, but while Somerset is near the top of a hill at an elevation of 1,080 feet above sea level, Milligan is in a narrow cup-like valley about 200 feet lower.

On May 1, 1914, the temperature at Somerset was 34° and at Milligan 29°. On May 2 it was 36° at Somerset and 28° at Milligan. On the 3d it was 41° at Somerset and 32° at Milligan. It is plain that frost would have damaged fruit and garden crops on all three nights at the valley station and probably on only one at Somerset.

(*p*) *Differences in minimum temperatures.*—In our forecasting of probable minimum temperatures in 1914 we found it of distinct advantage to know something of the average difference between the minimum temperatures at Columbus and the lowest in other sections of Ohio, under similar weather conditions.

Tables were prepared, therefore, showing the average differences between Columbus and points for which we wished to issue minimum temperature forecasts for April and May. These average differences were found when the weather conditions were favorable for free radiation, when the approach of a low pressure area caused rising temperature, when colder weather was approaching from the northwest, and finally when no marked change in temperature seemed probable.

It has seemed best to publish one of these tables, giving the average and extreme difference in minimum temperature in April and May, for the main fruit district or topographic stations. Some of the stations have been in operation but a short time, hence a 10-year average could not be obtained. Somerset was used as being characteristic of many of the hill orchards in eastern and southern Ohio. Table 5 gives the data referred to.

TABLE 5.—*Minimum temperatures lower than Columbus, at certain stations in Ohio, in April and May, 1914.*

Station.	County.	April.			May.		
		Average deficit for April for 10 years.	Average under radiation conditions, 1914.	Greatest deficit in 1914.	Average deficit for May for 10 years.	Average under radiation conditions (6 years).	Greatest deficit for any day (6 years).
		°F.	°F.	°F.	°F.	°F.	°F.
Delaware	Delaware	3.3	4.4	8	4.0	7.7	13
Green Hill	Columbiana	6.5	9.9	16	7.7	12.6	20
Haydenville	Hocking		6.8	11		[1] 10.7	[1] 16
Jackson	Jackson		3.9	11		[1] 5.0	[1] 12
New Lexington	Perry					[1] 0.4	[1] 9
Toboso	Licking		5.4	12		[1] 10.1	[1] 14
Somerset	Perry				1.5	3.2	13
Wooster	Wayne	4.1	5.7	11	5.0	9.1	16

[1] For 1914 only.

(*q*) *Daily range in temperature.*—In anticipating probable minimum temperatures when frost threatens, it is important to know the average fall in temperature from the warmest part of the day to the coldest of the following night.

Hence in Table 6 there has been given the average and extreme ranges in temperature from the maximum of one day to the minimum of the following morning in May for nine years, under conditions favorable for radiation, and for characteristic topographic stations in the State of Ohio.

TABLE 6.—*Average and extreme range in temperature in Ohio during May, 1909 to 1914, when an area of high pressure is centered over Ohio and adjacent States, giving radiation conditions.*

Station.	County.	Height above sea.	Location and topographical surroundings.	Range between P. M. maximum, and next A. M. minimum under conditions of free radiation.				
				First half of May.	Second half.	For whole month.		
						Average.	Greatest.	Least.
		Feet.		°F.	°F.	°F.	°F.	°F.
Bellefontaine	Logan	1,276	On hillside	24	26	25	39	13
Cadiz	Harrison	1,245	Near top of hill	26	25	26	37	11
Cambridge	Guernsey	803	In narrow valley	32	32	32	44	13
Camp Dennison	Hamilton	570	In broad valley	28	30	29	41	14
Columbus	Franklin	918	...do	19	20	19	29	7
Delaware	Delaware	896	In valley	27	30	28	38	10
Garrettsville	Portage	1,005	...do	30	29	30	49	9
Green Hill	Columbiana	1,135	...do	28	30	29	42	10
Haydenville	Hocking	700	...do	31	33	32	43	18
Hiram	Portage	1,260	On hill	22	22	22	37	13
Marietta	Washington	627	In broad valley	30	30	30	42	19
Milligan	Perry	875	In narrow valley	31	34	33	44	19
Ottawa	Putnam	720	Level prairie	25	26	25	40	7
Somerset	Perry	1,080	Top of hill	24	25	25	35	10
Summerfield	Noble	1,187	In valley	30	32	31	43	11
Toboso [1]	Licking	789	In narrow valley	32	34	33	44	21
Vickery	Sandusky	588	Slightly rolling	24	27	25	40	10
Waverly	Pike	590	Broad valley	30	32	31	40	18
Waynesville	Warren	700	Elevated plain	22	22	22	40	9
Wooster	Wayne	1,030	On hillside	27	29	28	45	12

[1] 2 years only.

As is to be expected, the range in temperature is greater at stations in the valleys than at those on the hills, the greater part of the difference being because of lower night temperatures rather than because of much difference in the daytime temperatures.

One marked example in this table is the difference between Hiram and Garrettsville, both in Portage County and not far apart but one in a valley and the other on a hill top.

Fruit men should keep a careful record of both maximum and minimum temperatures with reliable thermometers so as to determine what the average daily temperature fall amounts to, especially under frost conditions, because they can make a rough estimate of the probable lowest temperature that will be experienced.

(*r*) *Predicting minimum temperature from the dewpoint temperature of the evening before.*—It has long been believed that during conditions favorable for frost the dew point in the late afternoon would be approximately the same as the minimum temperature during the following night.

O'Gara in Oregon (Farmers' Bulletin 401) found that at no time in April and May, 1909, did the minimum temperature fall much below the dewpoint that was observed at about 8 or 9 o'clock in the evening. On the other hand, Cox (Bulletin T, p. 84) states that in the moorlands of Wisconsin "the dewpoint in the evening is no indication of the ensuing minimum temperature."

In order to give this matter a good test in Ohio dewpoint observations have been made at the special fruit stations and the results are given in Table 7. Not many stations were in operation in May, 1913, or March, 1914, but during April and May, 1914, records were obtained at 10 different points.

In the first five columns of the table the data are for the entire month, but in the last five columns the dewpoint and minimum temperature data are only for those nights which were favorable for free radiation, or, in other words, favorable for frost if the temperature should fall low enough.

The table shows that the minimum temperatures average higher than the dewpoints at Clyde and Columbus in April and May and at Mount Healthy in May, even on clear still nights.

At Jackson, Toboso, and Worthington, on the other hand, during May, 1914, the minimum temperature was never higher than the dewpoint on nights favorable for radiation. At some of the stations the minimum was never very much lower than the dewpoint, but in general the difference may be great enough to make this method of predicting the probable minimum temperature most unreliable.

For example, at Delaware in the month of May if we must feel that the minimum temperature may be either 7° higher or 10° lower than the dewpoint of the evening before, forecasts from the dewpoint can be of little value. At Toboso the minimum was 26° below the dewpoint on one night in May, 1914.

A study of the daily observations shows that when it is cloudy or partly cloudy in the evening and clears off during the night the morning minimum temperature will always be considerably lower than the evening dewpoint. On the other hand, if it clouds up during the night the minimum will generally not go so low as the dewpoint.

From a few dewpoint observations made later than 6 p. m. at Worthington it seems probable that later dewpoint observations may show a closer relation to the coming minimum temperature. Steps will be taken during the coming spring to have such records made.

Some of the records indicate that some of the wide variations between the dewpoint and minimum temperature may be because the wet-bulb temperature had not been accurately obtained, through failure to whirl the sling psychrometer long enough. But the fruit observers are all specially selected observers, and they were given

definite instructions as to the use of this instrument, and if they were unable to obtain accurate results it shows that when the average orchardist or truck grower attempts to use the sling psychrometer for determining the probable minimum temperature the results will be still more unsatisfactory.

Further studies seem to show that when the relative humidity is high on a clear, still evening the minimum temperature during the coming night will be lower than the evening dewpoint, and that when this relative humidity is low the minimum will not be so low as the dewpoint. Also that during nights when the minimum has run much below the evening dewpoint there has been a marked lowering of the dewpoint, although there are exceptions to this.—[Note by the author, Nov. 20, 1914.]

TABLE 7.—*Average and extreme differences between dewpoints observed at 6 p. m. and the lowest temperatures during the following night (for severe months and for those nights only when the conditions were favorable for radiation).*

Stations in Ohio.	For the whole month.					For nights when conditions were favorable for radiation.				
	Average.		Variation of minimum from the dewpoint.			Average.		Variation of minimum from the dewpoint.		
	Dewpoint at 6 p. m.	Minimum temperature during the night.	Average.	Greatest above dewpoint.	Greatest below dewpoint.	Dewpoint at 6 p. m.	Minimum temperature during the night.	Average.	Greatest above dewpoint.	Greatest below dewpoint.
FOR MAY, 1913.										
Columbus[1]	49.2	53.1	+ 3.9	22	− 8	40.4	48.4	+ 8.0	13	0
Columbus[1 2]	49.2	50.0	+ 0.8	19	− 8	40.4	43.1	+ 2.7	4	− 4
Delaware	50.2	47.0	− 3.2	6	−10	41.8	39.4	− 2.4	0	− 5
Marietta	51.4	49.9	− 1.5	11	−12	41.5	42.2	+ 0.7	11	− 4
FOR MARCH, 1914.										
Clyde	27.3	28.6	+ 1.3	17	−14	23.4	24.9	+ 1.5	17	−14
Delaware	29.0	26.8	− 2.2	7	−12	24.1	20.2	− 3.9	0	−11
Marietta[3]	32.8	31.9	− 0.9	12	−11	23.8	25.3	+ 1.5	4	− 3
Wooster	28.4	27.1	− 1.1	13	−11	24.8	22.4	− 2.4	8	−11
FOR APRIL, 1914.										
Clyde	38.2	38.6	+ 0.4	15	−10	35.4	37.7	+ 2.3	11	− 8
Columbus[1]	42.5	43.0	+ 0.5	15	−12	36.4	38.1	+ 1.7	7	− 5
Columbus[1 2]	42.5	41.6	− 0.9	13	−14	36.4	36.1	− 0.3	7	− 7
Delaware	42.3	39.8	− 2.5	9	−14	39.3	36.8	− 2.5	7	− 9
Green Hill	39.6	35.3	− 4.3	7	−24	32.9	27.7	− 5.2	0	−17
Jackson	47.7	41.5	− 6.2	15	−22	45.2	34.3	−10.9	0	−22
Marietta	45.6	41.6	− 4.0	7	−14	42.0	37.3	− 4.7	3	−10
Mount Healthy[3]	45.0	43.3	− 1.7	11	−25	39.8	38.2	− 1.6	5	− 7
Toboso	44.4	38.6	− 5.8	14	−33	43.1	34.4	− 8.7	6	−22
Wooster	40.2	38.0	− 2.2	12	−19	36.8	36.0	− 0.8	8	−12
Worthington[3]	45.8	42.3	− 3.5	9	−16	44.0	37.2	− 6.8	0	−13
FOR MAY, 1914.										
Clyde	49.1	51.9	+ 2.8	24	−11	43.3	47.2	+ 3.9	10	− 7
Columbus[1]	49.9	54.7	+ 4.8	15	− 4	43.2	50.8	+ 7.6	15	− 2
Columbus[1 2]	49.9	50.1	+ 0.2	14	−19	43.2	43.3	+ 0.1	6	− 5
Delaware	50.8	47.7	− 3.1	7	−18	45.7	42.1	− 3.6	7	−10
Green Hill	50.0	44.5	− 5.5	5	−20	43.4	34.4	− 9.0	1	−16
Jackson	58.3	51.1	− 7.2	2	−19	54.8	44.9	− 9.9	0	−19
Mount Healthy	53.2	54.7	+ 1.5	13	−14	48.4	48.9	+ 0.5	6	− 4
Toboso	61.7	47.4	−14.3	0	−26	59.6	39.2	−20.4	0	−26
Wooster	50.2	48.6	− 1.6	16	−16	44.8	42.7	− 2.1	6	−15
Worthington[3]	43.4	38.1	− 5.3	5	−12	42.6	36.4	− 6.2	0	− 9

[1] Dewpoint 7 p. m.
[2] Dewpoint at the Weather Bureau station minus the minimum temperature at the Ohio State University.
[3] For part of month only.

(*s*) *Diurnal temperature changes.*—It is well known that the highest temperature is generally during the day and the lowest temperature at night, and that on some days the range in temperature between the day and night is greater than on others. It may not be so well known, however, that the lowest temperature at night is usually just before sunrise and that typical weather conditions produce certain characteristic temperature variations.

To illustrate this point we have shown in figures 9 and 10 the records made by a self-recording thermometer at Delaware, Ohio, for the weeks of May 5 to 12, 1913, and May 11 to 18, 1914, respectively.

Temperature changes at any locality depend very largely upon the direction and force of the wind. If strong winds prevail from the northwest, there will be a fall in temperature, and if high winds prevail from the south the temperature will rise. In clear comparatively still weather the temperature will rise in the daytime under the strong sunshine and will fall to a low point at night because of free radiation of heat from the ground.

As a good deal of damage was done in Ohio by the cold weather of May 9 and 10, 1913, an analysis of the temperature changes for that week as shown in figure 9 will prove of interest.

On May 5, 1913, warm southerly winds prevailed in Ohio and the temperature was unseasonably high, as shown by the thermograph record in figure 9. The wind changed to westerly in the evening and there was an irregular drop in temperature.

On the 6th it was cloudy with strong northwesterly winds and there was only a moderate rise in temperature. It was cloudy at night and there was a very irregular drop in temperature.

The northwesterly wind continued on the 7th and although it was clear there was only a moderate rise in temperature. The wind decreased at night and as it was clear there was quite a rapid drop in temperature to 34° at about 5 o'clock a. m.

An area of high barometric pressure was central over this district on the morning of the 8th and there was a rapid and strong rise in temperature to 73° at about 3:30 p. m. It was clear in the afternoon and evening and the temperature began to drop rapidly, but it clouded up in the night and the wind increased, so that the temperature began to rise soon after 2 a. m.

The temperature increased very irregularly on the 9th because of cloudy weather and northwesterly winds. In the evening of the 9th the wind increased from the north and from about 4 p. m. to 6 a. m. of the 10th the thermograph curve shows the characteristic fall in temperature due to importation of cold air from the north in conjunction with the diurnal drop in temperature. The thermograph record made nearly a straight line in comparison with the concave curve of the records on clear afternoons with little wind.

The only way to predict the probable minimum temperature on nights like May 9, 1913, is by a study of the weather map. High wind continued all night and orchardists who tried to keep the temperature up by building fires found that the warmed air was carried away rapidly and that the temperature fell nearly as steadily where the fires were burning as outside.

The wind continued on the 10th, but as the sky was clear there was a moderate rise in temperature. However, the wind decreased the night of May 10, the radiation was rapid, and the temperature went considerably below freezing. Fruit men who failed to keep the temperature above the danger point during the night of the 9th/10th thought it useless to try to protect, or perhaps ran out of fuel, so that much damage was done through-

out Ohio. The few who did make the fight with plenty of fuel obtained splendid crops.

There was little wind on the 11th and with a large high-pressure area central over Ohio the thermograph curve for the 11th shows the typical rise and fall under anticyclonic conditions such as was recorded at Delaware.

(*t*) *Typical thermograph curve May 11 to 18, 1914.*—The characteristic temperature curve under conditions of high pressure and clear skies is shown during the last four days of figure 10. The rise in temperature is rapid in the morning and the curve has a convex shape. The highest temperature is about 3 p. m., and then there is at first a very rapid fall in temperature until about 7 p. m., then it falls more slowly until the lowest point at about 5 a. m. The afternoon and evening curve is concave in shape. These are the conditions under which frost is apt to occur.

On May 13, 1914, as shown on figure 10, there was very little change in temperature, due to rainy weather and a strong northerly wind. The wind shifted to northwest at about 10 a. m. on the 12th, causing a rapid drop in temperature from that hour, so that the highest temperature for the day was before 10 a. m. instead of in the afternoon.

In figure 11 the range in temperature is shown in a commercial orchard at Council Bluffs, Iowa, May 1, 1911, as shown in Iowa Experiment Station Bulletin No. 129. The solid line shows the temperature drop in an unheated part of the orchard while, beginning at 2:30 a. m., the dotted line gives the temperature in a part of the orchard protected by orchard heaters. These curves were drawn from hourly temperature observations. The heaters were lighted when the temperature had fallen to 29° and it immediately began to rise.

(*u*) *Predicting minimum temperatures by means of the afternoon or evening median temperatures.*—A study of any thermograph record will show that during periods of clear and calm weather, when an area of high pressure is centered over the district and the conditions are favorable for strong insolation in the daytime and for free radiation at night, there is a marked similarity in the daily curves. This is particularly well marked for May 14, 15, 16, and 17, in the last part of figure 10.

This being true, the question has been raised whether the halfway point in the temperature fall from the maximum of one day to the minimum of the next morning might not occur at about the same hour each evening on days when high-pressure conditions prevail.

A study was therefore made of the records of the self-recording thermometers at Delaware, Toboso, and Columbus, with very satisfactory results. It seems probable that the minimum can thus be predicted very accurately by taking the difference between the temperature at the time of the average median and the maximum for the day and subtracting that difference from the temperature at the average time of the median.

Table 8 shows the average time of the median temperature from April to November, inclusive, together with the earliest and latest median hours for the same months. At Delaware, for example, for the month of May, which is the critical frost month in that vicinity, the average median hour in 1913 was 7:36 p. m., and in 1914, 7:35 p. m. And more interesting still is the fact that the difference between the earliest median hours and latest median hours for May, 1913, was the same as for May, 1914, and was only 35 minutes. These figures are, of course, under conditions favorable for radiation or frost conditions.

At Toboso the variation is somewhat greater, but at Toboso the thermograph record is not quite so accurate as to the exact time correction. At Columbus the average for May, 1912, was 8:52 p. m., for May, 1913, 9:12 p. m., and for May, 1914, 9:15 p. m. The later median hour at Columbus is due to the less rapid drop in the temperature in the afternoon because of the city influence.

METHOD OF DETERMINING THE MEDIAN.

In Table 9 the method of determining the time of the median is shown for Delaware for May, 1913 and 1914. This table also shows the difference between the minimum temperature that would have been predicted by this method and that which actually occurred during those two months. On two days the minimum predicted from the median would have been 4° higher than the actual and on one day 5° too low, but the greater part of the time it would not have differed over 1°.

TABLE 8.—*Average times of median temperature, between the highest of one day and lowest of next morning, under conditions favorable for radiation.*

Data.	April, p. m.	May, p. m.	June, p. m.	July, p. m.	August, p. m.	September, p. m.	October, p. m.	November, p. m.
	At Delaware, Ohio.							
Average, 1912	......	......	......	......	......	......	5:30	6:24
Average, 1913	7:12	7:36	7:08	7:24	6:51	6:24	5:55	5:53
Average, 1914	7:11	7:35	7:34	......	......	......	......	......
Earliest, 1912	......	......	......	......	......	......	5:00	5:30
Latest, 1912	......	......	......	......	......	......	6:00	7:30
Earliest, 1913	6:30	7:15	6:00	7:00	6:00	5:30	5:00	5:30
Latest, 1913	8:15	7:50	8:00	8:15	8:00	7:30	7:00	7:15
Earliest, 1914	6:00	7:15	7:00	......	......	......	......	......
Latest, 1914	8:15	7:50	8:15	......	......	......	......	......
	At Toboso, Ohio.							
Average, 1913	7:22	7:42	7:22	7:53	7:10	6:51	5:57	6:20
Average, 1914	7:43	8:06	7:37	......	......	......	......	......
Earliest, 1913	6:30	7:00	6:00	6:30	6:00	6:00	5:30	5:30
Latest, 1913	8:00	9:00	8:30	9:00	8:30	8:00	7:00	7:15
Earliest, 1914	5:30	7:30	6:30	......	......	......	......	......
Latest, 1914	9:30	9:00	8:30	......	......	......	......	......
	At Columbus, Ohio.							
Average, 1912	9:15	8:52	......	......	......	8:36	8:23	7:35
Average, 1913	9:28	9:12	9:04	......	......	8:49	9:06	8:50
Average, 1914	9:30	9:15	8:38	......	......	......	......	......
Earliest, 1912	7:00	7:00	......	......	......	6:00	6:15	6:00
Latest, 1912	10:30	11:00	......	......	......	11:00	10:15	8:15
Earliest, 1913	7:45	8:00	7:00	......	......	6:15	8:00	6:30
Latest, 1913	11:00	10:00	11:15	......	......	10:00	12:00	10:00
Earliest, 1914	7:45	7:30	6:15	......	......	......	......	......
Latest, 1914	11:00	10:00	11:00	......	......	......	......	......
	Median between maximum at Weather Bureau office, Columbus, Ohio, and minimum at the Ohio State University.							
Average, 1912	......	10:15	......	......	......	9:32	10:51	8:20
Average, 1913	9:50	10:36	10:13	......	......	10:43	10:10	11:04
Average, 1914	10:34	10:48	10:18	......	......	......	......	......

TABLE 9.—*Method of determining time of median under conditions favorable for radiation, and difference between temperature estimated from median and from the dewpoint of the night before, and the actual minimum recorded at Delaware, Ohio.*

Date.	Maximum temperature.	Time maximum occurred.	Minimum temperature next morning.	Time that minimum occurred.	Median temperature.	Time of median temperature.	Minimum temperature estimated from the median.	Variation of estimated minimum from actual.	Minimum temperature estimated from dewpoint.	Variation of estimated minimum from dewpoint from actual temperature.
May, 1913.	°F.	P. M.	°F.	A. M.	°F.	P. M.	°F.	°F.	°F.	°F.
1......	81	4:00	43	6:00	62.0	7:50	47	+4	48	+5
2......	88	3:00	51	6:00	69.5	7:30	51	0	54	+3
3......	87	2:30	51	5:30	69.5	7:40	52	+1	54	+3
7......	67	2:15	34	5:00	50.5	7:40	35	+1	34	0
10......	54	2:00	27	4:30	40.5	7:30	27	0	26	−1
11......	63	3:00	29	4:30	46.0	7:40	30	+1	28	−1
18......	76	1:00	39	3:00	57.5	7:45	41	+2	44	+5
19......	71	3:30	48	1:00	59.5	7:45	49	+1	41	−7
24......	70	3:00	44	1:00	57.0	7:15	40	−4	46	+2
31......	80	3:15	54	3:00	67.0	7:30	54	0	57	+3
May, 1914.										
1......	57	1:00	29	5:00	43.0	8:00	33	+4	36	+7
2......	66	3:00	38	5:00	52.0	7:30	38	0	48	+10
6......	71	12:15	43	1:30	57.0	7:30	43	0	50	+7
14......	65	3:15	36	5:00	50.5	7:50	37	+1	41	+5
15......	64	1:30	33	4:30	48.5	7:45	34	+1	39	+6
16......	68	3:00	36	4:30	52.0	7:30	36	0	42	+6
17......	74	3:00	39	4:45	56.5	7:30	39	0	42	+3
18......	80	1:45	45	5:00	62.5	7:15	40	−5	44	−1
19......	84	2:45	46	5:00	65.0	7:30	46	0	52	+6
20......	86	3:30	50	4:30	68.0	7:30	50	0	52	+2
21......	87	2:00	50	5:00	68.5	7:30	50	0	57	+7
23......	77	2:00	47	4:30	62.0	7:30	47	0	47	0
30......	80	2:15	43	5:00	61.5	7:50	46	+3	44	+1

At Delaware the average time of median for May is 7:36 p. m.

This is a remarkable showing, and because May is the critical frost month it makes this method of great importance. In the latter part of Table 9 the minimum temperature as predicted from the 6 p. m. dewpoint is given for the same days, together with the difference between the predicted and the actual temperatures. This shows that while at times the dewpoint and minimum agree fairly closely, at other times the variation may be 10° above or 7° below the actual temperature.

In April and June the differences are not much greater than in May. In December, January, February, and March there are few well-defined periods with conditions favorable for free radiation with light wind.

(*v*) *Rules to be followed.*—When it is partly cloudy in the evening the actual time of the median will be later than the average. When a moderate wind is blowing this is also true, especially if the wind is from the northwest and there is an importation of cold air from that point.

In all cases when there has been a warm southerly wind blowing with a comparatively high temperature and the wind shifts to northwest with decidedly colder it is useless to try to predict the minimum from the median. The temperature curve then takes the form of that on the night of May 9, 1913, as shown in figure 9.

(*w*) *Suggestions for predicting minimum temperatures by means of the median for fruit growers and gardeners.*—The afternoon median temperature is the half-way temperature between the maximum of the day and the minimum of the next morning. In cloudy and stormy weather, or when strong southerly winds prevail, or when the wind is high from the northwest the time of the median varies so much that no attempt should be made to make predictions from it.

This is especially true when, after a period of warm weather, the wind shifts to northwest and the temperature begins to fall rapidly. This indicates the approach of a cool wave or cold wave, and the only possible way to forecast the probable temperature is from the daily weather maps. The orchardist or gardener who has crops in a critical condition in the spring or fall when these conditions prevail should lose no time in getting into communication with the Weather Bureau officials at such times.

But after the windy front of the cool wave has passed by, however, and the air is clear and still and the days are warm and the nights cool, then the probable minimum temperature and probability of frost damage can apparently be closely estimated for one's own orchard or garden by means of the median temperature.

To accomplish this, the difference between the temperature at the time of the half-way point, or median, in the evening and the highest temperature for the day must be subtracted from the median temperature. For example, if the highest temperature during the day is 68° and at the time of the median in the early evening it has fallen to 50°, the difference, or 18° subtracted from 50° leaves 32° as the probable minimum temperature during the night.

The average time of this median temperature, even under conditions of clear skies and still air, will vary slightly at different seasons of the year and in different localities.

In central Ohio, outside of the cities, the average time of the evening median will be at about 7:15 p. m. in April, 7:30 p. m. in May and June, 6:30 p. m. in September, and close to 6 p. m. in October and November. In July it is about 7:30 p. m., and in August 7:00 p. m. So far as we are able to determine it is not far from 6:30 p. m. in December and 7:00 p. m. in January, February, and March, although our observations and studies are not very complete in the winter months.

If a strong wind is blowing in the afternoon, or if it remains cloudy or partly cloudy until evening and then clears off, the time of the median will be from 30 to 45 minutes later than the averages above given.

If it should cloud up during the night after a clear afternoon and evening, the minimum will not be so low as is indicated by the median.

Records that are at hand indicate that the average time of median will be slightly later in the valleys than at higher elevations.

At Columbus, which represents a city station, the average time of median is later than at Delaware, and the variation between the earliest and latest hours is greater, but the error made by predicting the minimum from the average median is only slightly greater than at Delaware.

(*x*) *Instruments to be used.*—Orchardists and gardeners should provide themselves with reliable self-registering maximum and minimum thermometers. They may be the separate thermometers, as shown in figure 2, the best of which cost about $8 per pair. These are the standards used by the United States Weather Bureau. Or the two thermometers may be combined in one tube, as shown in figure 3. These cost about $5. They are somewhat easier to handle but are generally sluggish and not very accurate.

These thermometers should be exposed in a thin latticework shelter so that there will be a free circulation of air around them. Cheaper thermometers may be obtained, compared, and checked with the standards at critical temperatures, and then exposed in different parts of the

FIG. 1.—Instruments shelter and instruments at the special fruit-frost station at Delaware, Ohio. [Figure omitted.]

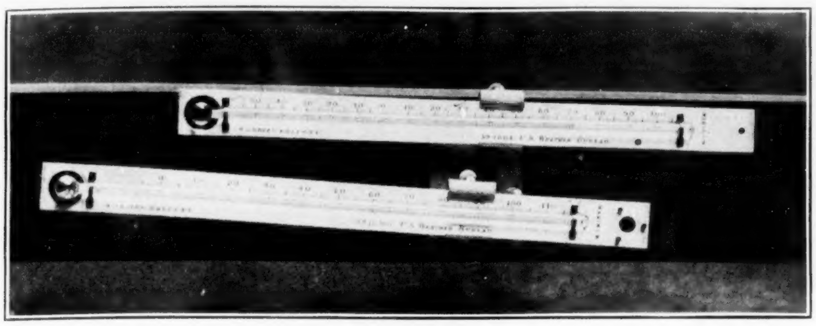

FIG. 2.—Maximum and minimum thermometers on the Townsend support as used at Weather Bureau stations.

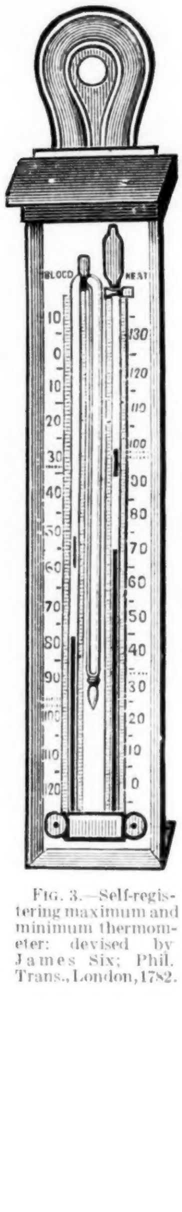

FIG. 3.—Self-registering maximum and minimum thermometer: devised by James Six; Phil. Trans., London, 1782.

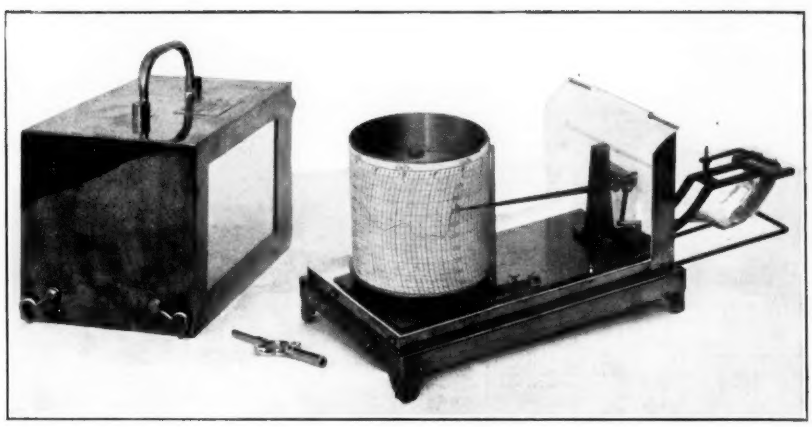

FIG. 5.—Thermograph, or self-registering thermometer, as used at many stations of the Weather Bureau.

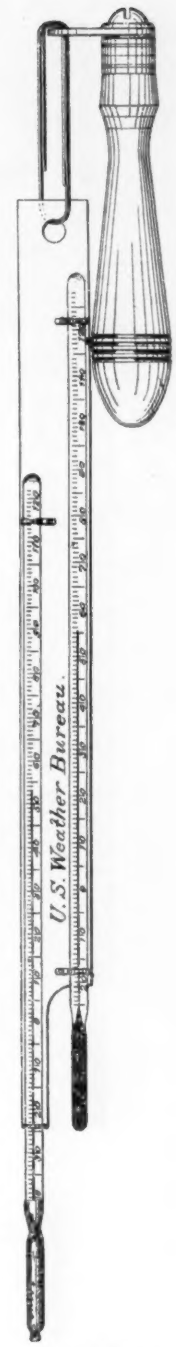

FIG. 4.—Sling psychrometer, Weather Bureau pattern.

FIG. 6.—A view in the orchard of G. H. Koeppel, Delaware, Ohio, at midnight, May 1, 1914. [Figure omitted.]

FIG. 7.—The Hamilton heaters in operation in the experiment station orchard at Wooster, Ohio. [Figure omitted.]

FIG. 8.—Troutman heaters in the orchards at Wooster, Ohio. [Figure omitted.]

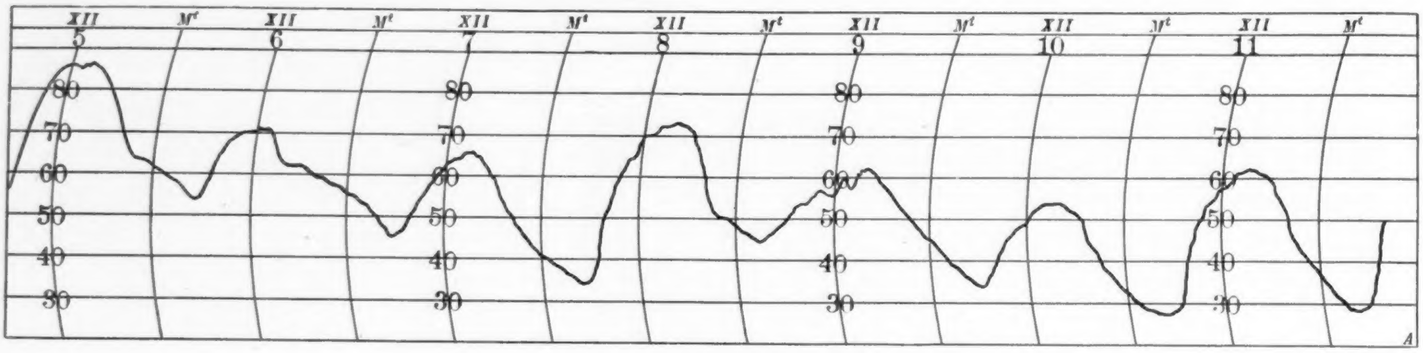

FIG. 9.—Thermograph record of May 5-12, 1913, at Delaware, Ohio.

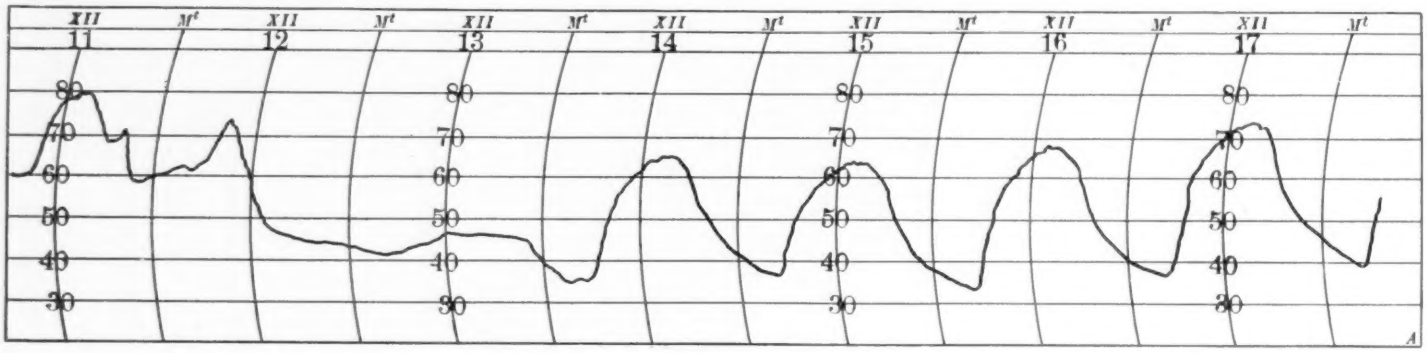

FIG. 10.—Thermograph record of May 11-18, 1914, at Delaware, Ohio.

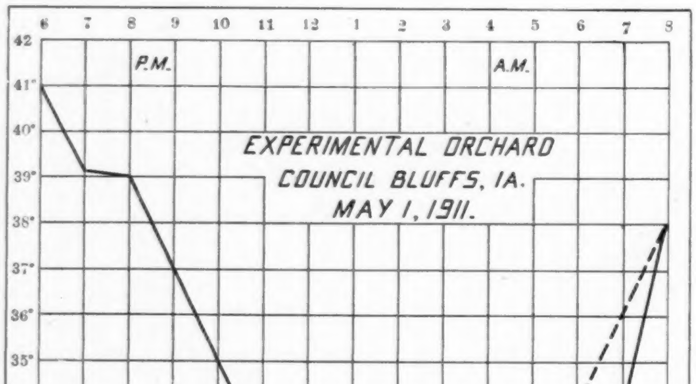

FIG. 11.—Temperature change in an unheated and in a heated area in Iowa.

FIG. 12.—Location of special fruit-frost stations in Ohio.

Fig. 13.—Average dates of last killing frosts in spring in Ohio.

Fig. 14.—Average dates of first killing frost in autumn in Ohio.

Fig. 15.—Average date of first bloom of apples in Ohio.

Fig. 16.—Average date of first bloom of peaches in Ohio.

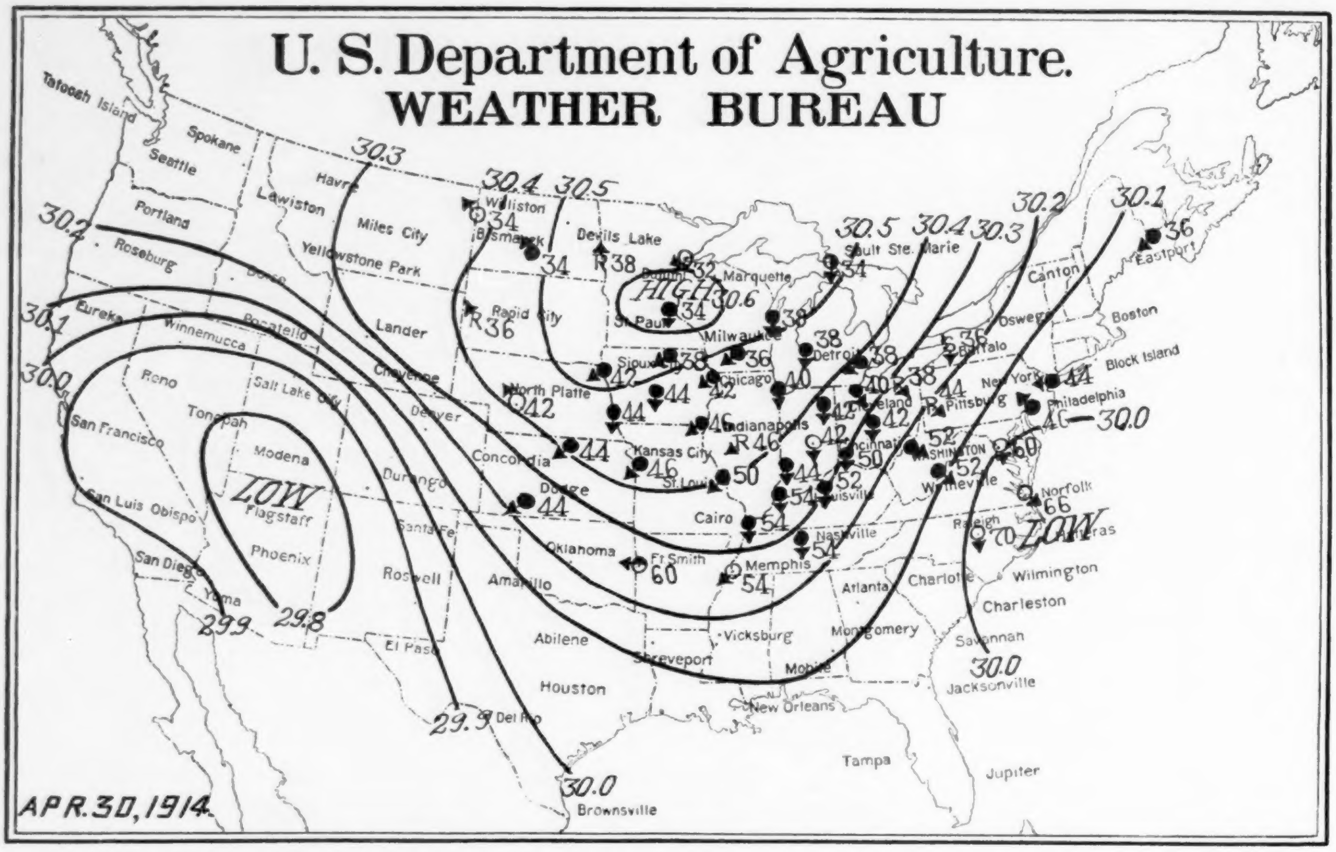

FIG. 17.—Daily Weather Map, 8 a. m., April 30, 1914. Showing an area of high pressure with a cool wave in the northwest that may be expected to overspread Ohio in the next 48 hours with general frosts. The lines are drawn for equal barometer pressure. The arrows fly with the wind, and show wind direction. The symbols indicate state of weather: ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; S, snow. The figures at the station shows current temperature.

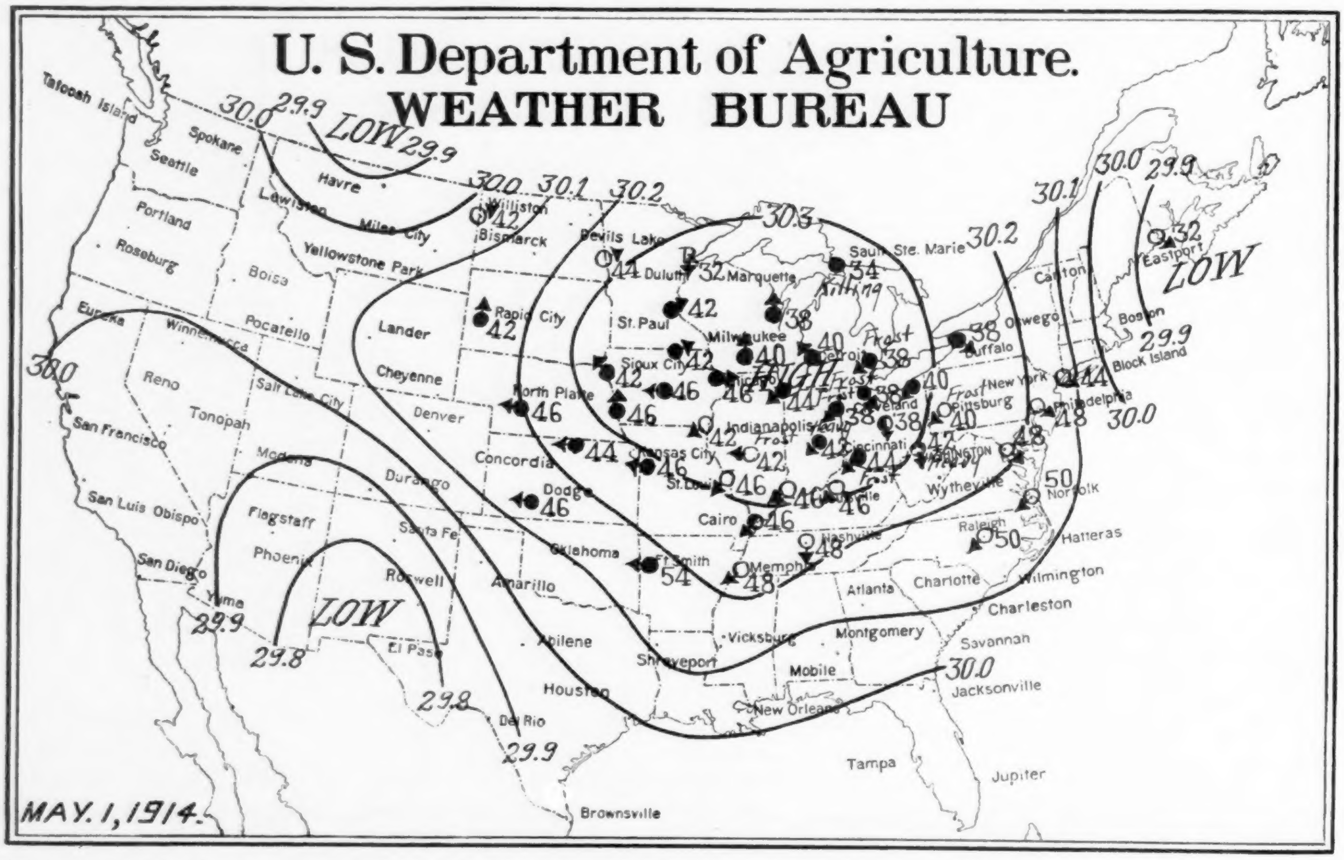

FIG. 18.—Daily Weather Map, 8 a. m., May 1, 1914. The high pressure area and cool wave is spreading southeastward and is causing frosts in Ohio. The lines are drawn for equal barometric pressure. The arrows show wind direction and fly with the wind. ○, clear weather; ◑, partly cloudy; ●, cloudy; R, rain; S, snow. The figures at the station indicate current temperature. Light, heavy, or killing frosts are indicated by frost, heavy, and killing.

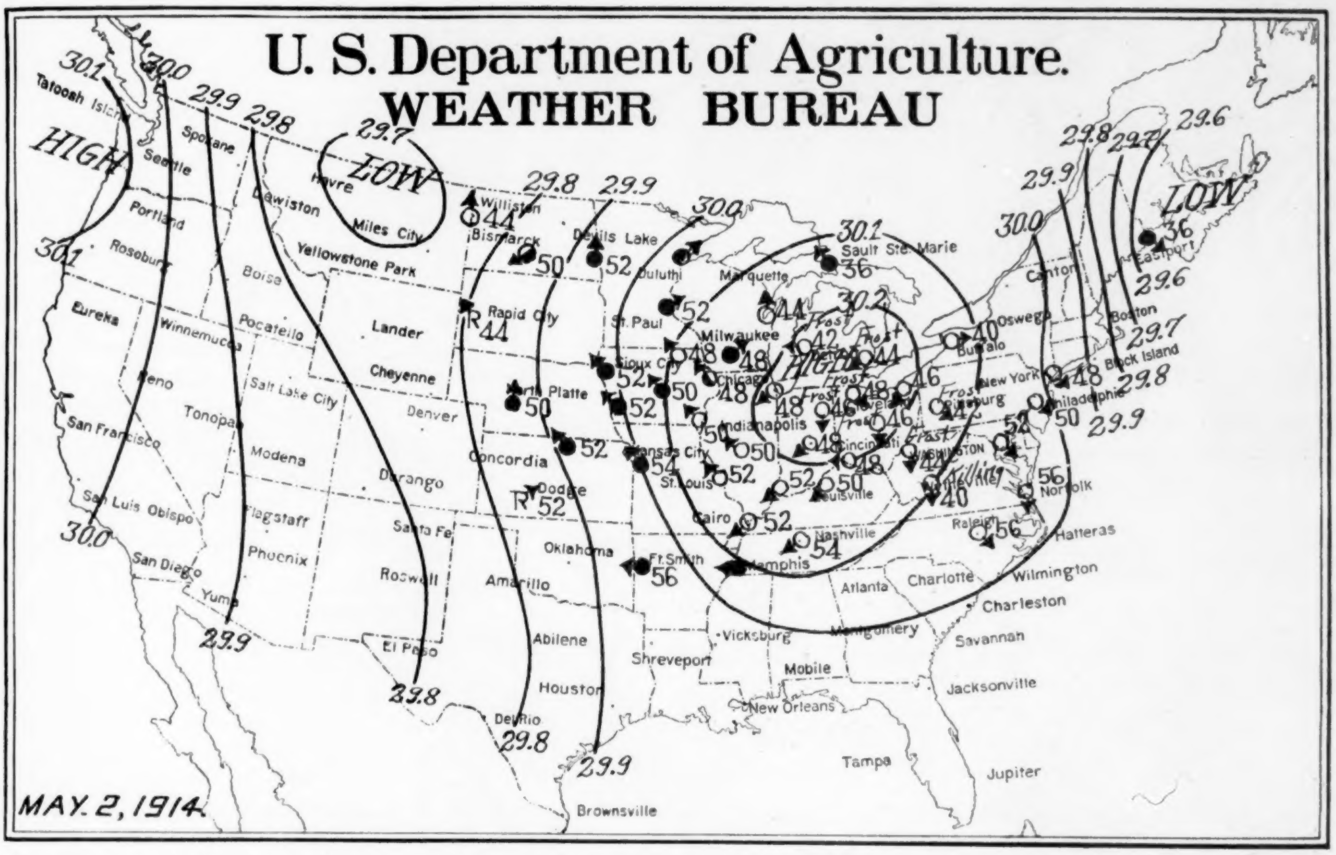

FIG. 19.—Daily Weather Map, 8 a. m., May 2, 1914. The high pressure area now overspreads Ohio and frosts are widespread. From now on the temperature will rise gradually as the high moves eastward. The lines are drawn for equal barometric pressure. Arrows show wind directions; symbols, state of weather; figures, current temperature; frost has occurred where the appropriate word is used.

orchard by hanging them against the tree or suspending from the branches. Thermometers should be exposed where the sun will not strike them and where they will have a free circulation of air, but always with a light protection over them to prevent too free radiation of heat from the instrument itself to the sky or other object. A thermometer hung out in the open will, in the sunshine, give a temperature much higher than that of the atmosphere, and at night it will be several degrees colder than the temperature of the air that surrounds it.

(*y*) *Prospective extension of the fruit-frost service and warning service.*—A few additional fruit-frost stations will be established in Ohio and steps will be taken to give the regular and special "frost warning" service to any fruit section or market-gardening section in the State where action is being taken to protect from frost damage.

VI.

AIR DRAINAGE EXPLAINED.

By CHARLES FREDERICK MARVIN, Chief of Bureau.

[Dated Weather Bureau, Washington, D. C., Nov. 20, 1914.]

1. Orchardists and others engaged or interested in agricultural pursuits, as well as physicists and meteorologists often employ the expression "air drainage" to designate certain features of atmospheric circulation attending the occurrence of frost during clear, still, cool nights in regions characterized by hill and valley conditions of topography. The popular conception of the actual phenomenon in question is often technically incorrect, and it seems worth while, therefore, to explain this particular species of atmospheric circulation in some detail in order that forecasters interested in the issue of frost warnings and orchardists and others who are prepared to prevent frost injuries by artificial protective measures may have a proper understanding of this interesting circulation. The faulty conception of air drainage is often conveyed by some such condensed statement as the following: The air on the higher slopes, cooled by contact with the surface soil or vegetal cover which is itself cooled by the active radiation under clear skies, *flows or drains downhill substantially as water would flow on the same slope.* This analogy of the flow of water is not materially inexact under particular conditions, but it is especially inappropriate and misleading as applied to the circulation of the air during the nighttime in such hill and valley regions as are now under consideration and that are frequently devoted to orchard and garden purposes. Air drainage on a hillside is *not* like the flow of water on the same slope because (1) air is a compressible gas and its flow is influenced by important thermodynamic actions as well as by gravity while the flow of water which is an incompressible liquid is determined practically by gravity alone; (2) water in place may flow completely away leaving the space it occupied vacant as regards water. Air, however, on a hillside, for example, can only change places with some other air, and then only under specific and prescribed conditions.[1]

2. In what follows an effort is made to clearly describe the interesting type of circulation commonly designated air drainage and to indicate the physical laws in operation.

[1] Prof. W. R. Blair, in his Five Year Summary of Free Air Data, Bulletin Mount Weather Observatory, 1913, **6**: 118-124, devotes some space to the discussion of mountain and valley temperatures in the vicinity of Mount Weather, and very correctly indicates the kind of circulation that can occur in such regions. In the present paper I am applying the term "air drainage," even though it be a misnomer, to the whole characteristic circulation of air on clear nights in hill and valley regions, whereas Prof. Blair, without specifically declaring himself on the point in question, has limited his use of the term to a real waterlike flow of air that may sometimes take place on relatively gentle slopes.

The author realizes that the explanation of air drainage now offered is at variance with the water-like-flow theory commonly entertained and found superficially discussed in even the best textbooks. This theory, nevertheless, is fallacious as applied to the conditions now under consideration, and will not stand critical analysis. It completely fails to explain the development of the vertical inversion of temperature. It asserts that a stream of cold surface air flows down the slope, filling up the valley with frigid air. How can there be a *thermal belt* on the hillsides if such a water-like flow of cold air exists? How can the alleged water-like flow of cold surface air on the hillside keep one part of the hillside warm and yet fill the whole valley below this level with much colder air? The *reductio ad absurdum* of this theory is brought out by the question: How can a stream of cold surface air flowing in a water-like fashion down a hillside produce a region like the so-called thermal belt that is warmer than any other locality, and how can the same stream flowing onward fill the whole valley below the thermal belt with frigid air?

3. While great diversities prevail in the topographic character of different regions causing corresponding modifications in the local circulation, yet the same general principles operate in all cases and a connected statement of the essential features under simple representative conditions will suffice. Consider, for example, an ordinary extensive valley, such as is to be found almost anywhere in a hilly, rolling country. The sides of the valley, as a rule, will be relatively steep, especially as compared with the bottom or floor, which for the present purposes may be regarded as comparatively level, although in fact it also slopes gently downward, as evidenced by the onward flow of a stream or river of water that may be found therein.

4. Observations tell us that during clear, still nights valleys of this character fill up to a considerable depth with a great riverlike mass of cold air. The temperature is lowest at the bottom, increasingly warmer at intermediate layers and warmest at the surface of the aerial river. Above the river the temperature of the air decreases more or less rapidly with increase of elevation. The term "air drainage" from the present point of view, is the name assigned to the local circulation that is able to create and to build up during a nighttime a deep river, or lakelike mass of cold air similar to that just described.

5. We may for a moment consider another species of air drainage, namely, the sluggish flow of the whole river of cold air down the nearly level floor of the valley on its way to the sea. This sluggish flow does take place and is fairly like that of water. Also in the afternoons and early evenings, while the surface air is still warm and the surface temperature gradient is not as yet strongly nonadiabatic, the flow of cooling surface air even on the steeper slopes may somewhat resemble the flow of water on the same slopes. Nevertheless, both the sluggish flow of the river of cold air and the waterlike flow of portions of surface air in the afternoons constitute for the orchardist relatively unimportant species or aspects of air drainage and need no further mention here.

6. In order to fully understand the circumstances leading to the formation of the river of cold air, it is necessary to begin with a brief account of the condition of the air in and over the valley during the preceding day and incidentally to explain the significance of the adiabatic relation of atmospheric temperatures.

7. In the course of a bright, sunshiny day with little or no wind, the free air occupying the lower strata of the atmosphere for a depth of one or two thousand feet or more, is practically in adiabatic equilibrium, which means

that the air temperature will fall approximately 1.6°F. for each 300-foot increase of elevation. These strata get into this condition because this is approximately the rate at which a heated mass of air and vapor will cool when it ascends in the free air and expands and does work in pushing aside the surrounding air, but *without any condensation of vapor or any gain from or loss of heat to its environment.* When, therefore, the air in contact with the heated soil and vegetation becomes overheated relative to the surrounding air it ascends, cooling at the adiabatic rate and comes to rest, possibly at an elevated point, where its own temperature and that of the surrounding air are the same. After this convective circulation has continued actively for several hours during a bright, sunshiny day, a considerable portion of the free lower strata not only acquires large additions of heat, but also attains nearly or quite the adiabatic condition of equilibrium. Nevertheless, adiabatic equilibrium is exceptional and limited, both as regards the amount of air involved and the length of time the condition will be maintained. In fact, it may be said that nearly every influence affecting the temperature of air masses opposes the attainment of the adiabatic relation of temperatures. The nonadiabatic state therefore is the rule. In the nonadiabatic atmosphere the air higher up is potentially too warm; *vice versa,* the air lower down is potentially too cold to be in the adiabatic relation. In the nonadiabatic atmosphere, therefore, the warmer air higher up acts as a ceiling and stops the ascent of air from below that has been slightly heated. Conversely, the colder air lower down acts as a floor and effectually stops the descent of air from above that has been slightly cooled.

8. These relatively intangible thermodynamic principles wholly govern and determine the flow of air in the hill and valley regions we are now considering. A steep hillside down which water would flow in the most tumultuous fashion is not a hillside for the flow of air in any sense of the word. The hillside may be replaced by a tremendous cliff with a vertical face, but the effect on the flow of the air will be immaterial in so far as the change in the angle of the slope is concerned. *The function of the hillside in connection with the phenomenon of air drainage is simply that of a cooling agent.* In order to explain this action clearly we need to consider further the surface and free-air temperatures and the cooling influences due to radiation.

9. Even though the *free* air over our valley region during midafternoons of bright sunshine may nearly attain adiabatic equilibrium, nevertheless the *surface* layers on the hillsides rarely or never reach this state, because the strong surface heating maintains the upper layers for the time being at too high a temperature; higher, in fact, possibly, than the adjacent *free* air at approximately the same level. An interesting result of this abnormality will be discussed further on.

10. As soon as surface cooling has once fairly set in with the decline and setting of the sun, the convective ascent of heated air at once stops or is confined to very narrow limits. At this stage the whole mass of entirely free air is relatively warm and probably almost, but not quite, in the adiabatic state. These free-air masses, however, so long as they remain in place can lose their heat only by the slow process of gaseous radiation. Radiation from the soil and vegetal cover, however, is much more rapid. Consequently, the surface layers of air everywhere on the hillsides and in the valleys lose temperature rapidly and are soon too cold to be in adiabatic relation with any of the free air. While strictly speaking the rate of loss of heat by radiation should be slightly greater the greater the elevation, nevertheless the small advantage on this account in favor of more rapid cooling in the higher levels is quite inadequate to materially diminish the original relative excess of heat in the surface layers on the upper slopes. We may fairly say the rate of cooling by radiation of the surface air from top to bottom of the slope is practically the same when the conditions of surface cover and other things are the same. The surface air at the bottom of the slope is relatively colder to begin with than any of the surface air higher up and continues to remain so.

11. Observations at Mount Weather show that the surface air at the crest of the ridge is materially warmer, potentially, than the air lower down or at the bottom of the valley, especially as night approaches. In fact, the observations indicate that by nightfall, for a short time at least, the whole surface layer of air on the hillside from top to bottom has practically the same temperature.

12. With all the foregoing considerations in mind we are forced to the conclusion that air drainage on a hillside is very unlike the flow of water on the same slope. What takes place may be described as follows: The surface air at the bottom of the valley, cooled by its contact with the soil and cooling vegetal cover, remains practically where it is and continues throughout the night to get colder and colder, undergoing, of course, a small contraction in volume. The layers of free air immediately above the vegetal cover and cold surface air at the bottom of the valley at first remain relatively warm, because, having no contact with cooling surfaces, such free air cools chiefly by radiation and at a very small rate. At the sides of the valley, however, this relatively warm free air is closely adjacent to the cold and cooling surface layers at the same and slightly higher levels. A convective exchange of place of these portions of air begins as soon as small differences of density occur. The cool surface air from the slopes flows or drains slowly down and out, nearly horizontally on top of the colder denser air already filling the bottom of the valley. The warm free air moves in upon the slopes and in turn is itself cooled by contact with the surface cover only to exchange again with warmer adjacent free air. A similar interchange between the cooling surface air in contact with the hillside and warmer adjacent free air will take place in each succeeding higher and higher level.[2] Thus a continuous interchange is established probably by numerous fluctuating streams of flow between the cooling surface air at the sides of the hill and the great reservoir of warm free air of the valley.

13. It is not to be supposed that relatively small portions of slightly cooled air, retaining individuality, flow from the hillsides to positions far out in the free air. Every leaf, twig, blade of grass, or other object freely exposed skyward acts as a slow cooling agent to the small portions of immediately contiguous air. Numerous small streams of flow must necessarily exist. Intermixing at the separating surfaces of flow at once sets in and, aided by dynamic heating, not only warms up the cooler air and cools down the warmer air but tends to stop the motion. Nevertheless the average temperature of the mixture is lower than that of the other air near by, so that progressive interchanges keep going on. In the meantime the hillside, acting as a cooling agent, is continually dissipat-

[2] Data are lacking from which to determine the probable distance between the different strata of convective exchange. This difference will depend partly on how rapidly cooling takes place on the hillsides and partly on how greatly the temperature gradient differs from the adiabatic. For the present purpose the rate of cooling is relatively slow, consequently slow convective motions will occur for small differences of temperature and density. Since the temperature gradient in the surface layers is widely different from the adiabatic, any considerable descent of slightly cooled air along the surface or otherwise is impossible; the interchange with the warmer air must take place at many different levels, which no doubt frequently shift positions with temporary changes in rates of cooling or with any one of many other disturbing influences that may arise.

ing the heat brought in and adding new quotas of ever colder and colder air to keep up the circulation.

14. Under certain conditions it may sometimes occur during the afternoon or early evening that the surface air high up on the hillside is warmer than the adjacent free air. These temperature relations will cause the warm surface air to convectively change places with the adjacent cool free air, and to this extent the rate of cooling of the surface air on the upper portion of such slopes will be increased for a time. Just as soon, however, as the temperature of this surface air has become the same as that of the adjacent free air at nearly the same level, the convective exchange, with a cooling effect, will cease, but a similar exchange will set up again in the reverse direction with a warming effect when the temperature of the surface layers has been reduced still lower as a result of radiation.

15. It therefore appears that during the nighttime the warm free air facing the slopes of a valley, acts as a great reservoir of heat which is drawn upon by the operation of the convective exchanges described in the foregoing to conserve the temperature of the adjacent hillsides and to prevent the fall of temperature that would otherwise result from the loss of heat by nocturnal radiation under clear skies—a fall that does occur at the bottom levels of the valley where convective exchanges are impossible or the quantity of free air is too small to afford material protection. The circulation described also forms, little by little during the nighttime, the stagnant river or lakelike mass of cold air that fills the lower levels of the valley to a greater and greater depth.

16. The surface of the river of cool air is defined by the simple condition that its temperature is greater than that of any adjacent air either above or below. This surface, moreover, is essentially horizontal except along the shore lines where the surface rises to meet the bank tangentially. In this region cooling is going on somewhat rapidly and the adjustment to equilibrium is not as yet complete. The shore lines of this river in the early morning hours locate the much desired thermal belt of the orchardist. How deep the river will be at dawn under average climatic conditions in a given valley, can best be established only by suitable observations and interpolations, although estimates thereof may probably be made from a careful study of the several physical elements of the problem.

17. The foregoing clearly indicates, it is believed, the essential characteristics and principles of air drainage as it actually occurs under hill and valley conditions, and the reasons thereof. Many minor details have necessarily been omitted, and the differences in results with essentially different conditions of topography, while affording interesting applications of the principles presented above, are not appropriate to the present discussion. The point of chief importance, perhaps, is the fact that the source of the heat that conserves the temperature of the slope surfaces is the great volume of warm *free* air facing the slope. The volume of this air near the bottom of the valley, as already stated, is too small to give material protection, such as is afforded at intermediate levels. While unlimited masses of free air may be available higher up, the temperature in these levels, even at midafternoon, may be lower than that of the adjacent surfaces. Consequently at first these are rapidly cooled by both radiation and the convective exchanges. Later on these exchanges have a warming effect and conserve the surface temperatures against radiation losses, but the actual temperature may be much below the requirements of agriculture.

VII.

PROTECTION AGAINST FROST IN GEORGIA.

By CHARLES F. VON HERRMANN, Section Director.

[Dated Weather Bureau, Atlanta, Ga., Nov. 27, 1914.]

The first shipment of peaches from Georgia by refrigerator cars on a commercial scale was made in 1884. The rapid increase of the industry is probably best indicated by the comparative number of trees of bearing age, since variations in the quantity of product is so largely dependent upon favorable or unfavorable climatic conditions. The number of peach and nectarine trees in Georgia in 1890 was 2,787,546, in 1900 it was 7,668,639, and in 1910, 10,609,119. The total value of orchard fruits produced annually now exceeds $3,000,000.

The principal peach-growing districts of Georgia lie northwest and south of Atlanta. According to the census of 1910 the number of peach trees in each county in the main sections were as follows:

Northwestern section.		*Fort Valley district.*	
County.	Number.	County.	Number.
Walker	283,000	Spalding	127,000
Chattooga	436,000	Upson	195,000
Whitfield	269,000	Monroe	145,000
Floyd	411,000	Meriwether	142,000
Gordon	322,000	Crawford	378,000
Bartow	586,000	Taylor	271,000
Pickens	187,000	Macon	576,000
Cherokee	163,000	Jones	432,000
Cobb	281,000	Houston	1,385,000

The development of methods of protection from frost has kept pace with the rapid growth of horticultural interests in Georgia. An impetus was given to the study of this question by the accidental production of a full crop of peaches in one orchard near Fort Valley in 1888, while the crop was a general failure throughout the State on account of late spring frosts. The woods west of this orchard (the Hiley orchard) were accidentally fired the night before the frost, and thick smoke settled over the orchard which helped to produce a full crop of peaches. A limb containing 35 peaches cut from an Elberta tree in the Hiley orchard was photographed and for many years figured in all the nursery catalogues.

Ten years later, in 1898, the use of smudge fires as the most efficient and practical means of protection from frost was quite general in Georgia, with varying degrees of success. The fuel most frequently used was coal tar with pine straw, and 20 to 25 fires to the acre were needed to produce a sufficiently dense smoke.

The severe freeze of February, 1899,[1] during which temperatures below zero, Fahrenheit, were experienced even to the southern limit of the State and which resulted in the death of many trees, marked decline in the shipment of peaches, and seems to have discouraged further efforts to protect the peach crop. Since 1899 the following years only have given full crops without the necessity for protection, viz: 1901, 1904, 1908, 1912, and 1914.

During the remaining 10 years the crop was generally a partial or complete failure on account of freezing weather in early spring or late frosts. The whole matter of protecting peaches in Georgia is now in a state of

[1] See MONTHLY WEATHER REVIEW, February, 1899, p. 69, and Chart XIII.

desuetude. Only here and there occasional efforts are made to protect peach orchards, generally by the older methods. There can be no doubt that by the application of the newer methods of protecting orchards most of the crop failures since 1890 could have been avoided, and it is unfortunate that peach growers have not kept abreast of the times in this respect.

The reasons for this notable lack of interest in the subject at present may be stated as follows:

1. A lack of knowledge of the newer and more efficient methods of orchard protection now successfully used in the West, which depend not so much on the protection afforded by smoke as on the actual warming up of the air in the orchard.
2. Lack of faith in the efficiency of the newer methods.
3. The expense involved, since it is known that devices for heating the air are expensive; their value depends upon a comparatively still air and numerous well-distributed fires. The cheapness of fuel and labor in Georgia, however, should not be forgotten.
4. It is though that peach trees can not bear full crops in successive years, therefore a full crop is not expected more than once in three years. The profits during the full years overbalance the losses during the lean years.
5. The lack of cooperation among neighboring orchardists.

In the early part of the year 1914 this matter was brought to the attention of about 60 of the largest peach growers in Georgia, by the official in charge of the local office of the Weather Bureau at Atlanta, and bulletins on the subject were widely distributed.

The use at present made of the frost warnings in Georgia, as far as known, is limited to efforts to protect small fruits, chiefly strawberries, of which 1,262,000 quarts were produced in 1909; also to protect truck crops and tobacco beds in the springtime by the usual methods of covering with straw, pine needles, cloth, or earth. In the aggregate the resulting saving must be considerable. The frost warnings when issued with the daily forecasts are available by free telephone distribution to over 75,000 people. The special frost warnings, however, are issued to only 23 addresses. In autumn the frost warnings are utilized not to protect, but to enable a farmer to gather as quickly as possible the crop threatened, as, for example, bell peppers and tomatoes, which are left on the plants as long as possible.

It is evident that in Georgia a much greater utilization of the frost warnings is possible.

VIII.

PROTECTION FROM FROST IN UTAH.

By ALFRED H. THIESSEN, Section Director.

[Dated Weather Bureau, Salt Lake City, Utah, Nov. 27, 1914.]

There are two seasons in Utah when agricultural products are subject to frost. The first is in the spring, from April 1 to May 15, when apricots, cherries, peaches, and sometimes apples need protection. The second is in early fall, when flowers, tomatoes, onions, and alfalfa seed are in danger.

The temperatures as obtained from the ordinary records of cooperative observers give a very accurate idea as to the period when fruit may be menaced by frost in spring, as the thermometers are exposed at about the same elevation as the zone of greatest fruit production. The condition to be most feared is that with a low pressure area over Colorado and a high pressure area over the Northwest. This means the importation of cold air from the north accompanied by a settling of cold air from higher altitudes, and as this condition is usually attended by wind, therefore protection by orchard heaters is very difficult.

The fruit districts center around the following places: Tremonton, Brigham, Ogden, Salt Lake City, and Provo, all on the western slope of the Wasatch Mountains and in the Great Salt Lake drainage area. During the frost period in the spring telegraphic reports are received from the above-named places every day, and an attempt is made from this data and the weather map to forecast the probable minimum temperatures which will occur at those places on the following morning. In a country of such diversified topography as Utah, there is considerable difference in temperature within short distances. The growers, to take advantage of the frost warnings, study their local conditions as compared with the "key stations." The forecasts are given for the key stations, and if a grower has found that his place is consistently warmer or colder than the key station he can then act intelligently when warning for his key station is received.

The method of protection is by heating with the orchard heater, using either coal or oil as fuel. It can not be said that protecting the fruit from frost is universal in Utah. As a matter of fact, only a few farmers, comparatively, are convinced of the practicability of this method or any other method of protecting their fruit. There is a sufficient number, however, who have faith in the oil pot or coal pot, so that the Weather Bureau cooperates with them, as some have very large orchards.

The temperatures obtained by cooperative observers will not indicate very accurately the period at which protection of tomatoes and alfalfa seed in the fall is needed. These crops grow low, and at the special key stations, Willard, Roy, Nephi, Mills, and Deseret, the thermometer shelters are placed on the ground so that the thermometers will indicate the temperature of the surrounding vegetation more nearly than if mounted in their usual position 4 feet above the ground.

The tomato-growing industy is very large and is encouraged by the presence of large canneries in this State. Tons of tomatoes are raised every year, and frequently the last of the crop is spoiled by fall frost, if not protected. Tomatoes, onions, etc., are protected by smudges which are quite effective as very little wind accompanies early fall frosts. The alfalfa seed crop is protected in a much different manner. When alfalfa becomes frosted the seed is blackened, in which condition it sells at a much lower price than the bright, unfrosted seed. It is said, however, that its germinating quality is uninjured. The alfalfa seed grower as soon as he learns that frost of sufficient intensity to blacken the seed is expected, puts to work in the field all the mowers he can, then he stacks the grass. Only a small percentage of the seed is frosted when in this condition, and the crop will then have a high selling value.

It may be asked: Why does not the grower cut his seed earlier? Alfalfa seed matures very unevenly, therefore, an early fall frost catches the seed in all stages of growth, part being in the ripe stage, part fully developed but full of sap, and part not far enough advanced to germinate. During this period, about 10 or 15 days before the crop should be cut, the seed increases in weight from 50 to 100 pounds per acre every 24 hours. The grower, therefore, is tempted to allow the plant to remain standing until the last minute in order to secure this increase, and as seed is now selling for about 12 cents a pound, the increase in weight is valued at from $6 to $12 per acre per day.

The Weather Bureau places thermometers in alfalfa and tomato fields every fall about August 20 and receives telegraphic reports daily from all stations of their temperatures, and the information is handled in the same way as with fruit in the spring.

IX.

NOTES ON FROST PROTECTION IN THE VICINITY OF KNOXVILLE, TENN.

By J. F. VOORHEES, Local Forecaster.

[Dated Weather Bureau, Knoxville, Tenn., Nov. 28, 1914.]

Protection from frost has not been practiced in this State except on a small scale and generally in a more or less experimental way. A few orchardists have fired their orchards regularly for several seasons and a number of others have built fires occasionally. In most cases there has followed a crop of fruit where the firing was done, but usually some of those who did not fire have also had a crop which makes it very hard to determine just what the benefit of the firing has been. The general opinion, however, seems to be that firing pays, and the amount of firing done each year is, I believe, on the increase.

The topography here is such that it is impossible, except in rare cases, for orchardists to cooperate, as the orchards are widely scattered, each on its own hillside.

A variety of fuels have been used with about equal success as far as protection was concerned. It appears, therefore, that the cost of fuel and work of handling it would be the factor that would determine which is best for any individual.

The principal fuels used here are straw, old stumps, coal, and crude oil. Where there are many stumps in an orchard they should of course be used, as by that means the stumps are removed economically. Soft coal has been the favorite fuel in this region so far, because for a given amount of heat it is much cheaper than crude oil at prevailing prices. The oil is being used in some cases because of the greater ease in handling, but in one experiment at the University of Tennessee Fruit Farm, when a cold wave arrived during a snowstorm, the oil failed because the falling snow caused it all to pop out of the container in which it was burning.

The need for frost protection is very irregular. In some years no protection is needed while other years occur in which several firings would be necessary to save a fruit crop. Sometimes the freeze comes on a still night when protection is comparatively easy, and again it comes with a high wind that makes protection very difficult if not impossible.

Under these conditions it is difficult to get any but those whose living depends on the orchard to take the trouble to prepare to protect from frost. Still the number who try to protect their fruit is increasing and should be increased many fold.

X.

FROST FORECASTS AND PROTECTION IN OREGON, WASHINGTON, AND IDAHO.

By EDWARD A. BEALS, District Forecaster.

[Dated Weather Bureau, Portland, Oreg., Nov. 28, 1914.]

Those receiving the most benefit from frost warnings are the horticulturists who have commercial orchards. No one else is prepared to do anything in the way of protection. Frost warnings are of no benefit to farmers who do not protect their crops. I judge that not over 10 per cent of the fruit growers use protective measures, but as the crop runs into millions of dollars this 10 per cent amounts to several hundred thousand dollars.

Two classes of frost forecasts are made here: One wherein the information is conveyed in general terms, e. g., light, heavy, or killing frost expected, and the other in specific terms, by the statement that the minimum temperature next morning will be 26°, 28° or 30°, as the case may be. The latter forecast is sent to a central point where protection work is done, such as Medford, Oreg., North Yakima, Wash., and Boise, Idaho. When received at these places a local man amplifies it to fit still more restricted localities; and when the distribution is made, which is done by telephone, practically every horticulturist in the neighborhood knows just what temperature to expect, and can prepare himself accordingly. By means of these forecasts many orchardists have saved a crop that would otherwise have been a total loss. Just what credit the Weather Bureau should receive can not be accurately determined. It is probable it will amount to $100,000 or more every year when damaging frosts occur. Some of the orchardists would save their crops if they did not get the warnings, as they always are on the watch for frosts and get very little sleep on this account during the frost season, but the majority depend upon Weather Bureau warnings and at times they would suffer severely without them.

Most of the orchardists use oil burners to heat their orchards, but a few use wood. A great many use prunings for their first fire, and after they are burned no more protection work is done, consequently they are prepared for only one frost, and if another occurs they lose their crop and have nothing to show for the work previously done.

Orchard-heating systems are slowly improving. The first mistakes were in not having enough pots to the acre. After these were increased it was found that the style in use gave the most heat shortly after being lighted, whereas early in the morning when the most heat was wanted the fires were burning low and not enough was obtained. As fast as improvements are being made in the heating apparatus the number of orchardists engaged in the work increases.

It has been proved that the temperature can be raised by 6° or even 10°F. in an orchard by heating methods, and this is sufficient in every case, so far as I know, to save a crop in the North Pacific States, where on frosty mornings the temperatures never go more then 10° below the freezing point.

Some think the orchard business has been overdone in the North Pacific States; hence during the last two years not so many new orchards have been planted. For the preceding five or six years the increase of orchard acreage had been enormous. During the next two or three years the new trees then coming into bearing will make the necessity for frost warnings greater than ever.

Orchard heating is used mostly by the apple growers, less by those who raise pears, and still less by the peach, prune, and cherry growers.

The localized districts now in operation are known as the Rogue River Valley, with Medford, Oreg., as the central point; the Yakima Valley, with North Yakima, Wash., as the central point; the Boise Valley, with headquarters at Boise, Idaho. A new district will be operated next spring to take in the orchards in the neighborhood of Walla Walla, Wash. In this latter district the trees are just coming into bearing and these orchardists were not heretofore interested in protection work.

XI.

FROST AND FROST PROTECTION IN FLORIDA.

By ALEXANDER J. MITCHELL, Section Director.

[Dated Weather Bureau, Jacksonville, Fla., Dec. 1, 1914.]

Many products grown in Florida have their natural habitat in lower latitudes; this, in conjunction with the efforts of fruit and vegetable growers to force production throughout the winter months, in order to realize the highest market prices, entails extra precaution in Florida as an essential to success.

The resistant power of products grown in most of the peninsular section of Florida ranges from that of the tomato, bean, and Irish potato (which are frequently damaged when thermometers, properly exposed, indicate temperatures in the thirties) to that of citrus fruits (which withstand temperatures well down in the twenties, provided the duration of the cold weather is not prolonged). A temperature of 25°F. and somewhat lower, during the first night of a cold wave, results in no damage to citrus fruit; but a two-night cold wave with a temperature fall to 25°F., or below, before midnight, will be attended by disintegration of some fruit—particularly in sections whose soil radiates heat freely, and where groves are remote from large bodies of water, or do not enjoy other factors that tend to sustain temperatures during abnormal conditions.

The growing period in Florida, which recognizes the necessity of protection, has no seasonal limitation. For some winter and spring crops, such as vegetables of various kinds, seeding begins during August or early in September; in order to circumvent possible disaster, resulting from unfavorable weather, seed beds are constantly being renewed, from which source fresh plants are drawn, as the exigencies of winter may require. Frosts occur occasionally over the interior of the extreme northern portion of the State during the last week of October, but the temperature is rarely low enough to damage any material crop before the second or third decade of November. It may be well to add, however, that radical departures from normal conditions have occurred over all sections of the State during the last two decennia, namely, December, 1894, and February, 1895 and 1899, resulting in destructive frosts throughout the mainland. These extreme conditions were epochs in the climatic history of the State. February 15, is an average date of the last dangerous frosts over most of the lower peninsula; the vagaries of the climate are indicated in the possibility of frost as late as the first week of April—fortunately so rare, however, as not to merit attention. March frosts damage fruit bloom over some northern counties; frost during March of the current year caused serious damage in Florida to vegetables as far south as the twenth-seventh parallel.

The pressure distribution that results in the late spring frosts of these low latitudes is worthy of attention. Preceded, usually, by a shallow barometric depression over the lower valleys (and not infrequently along the Gulf margin) the area of moderately high pressure (the crest possibly not more than 30.2 inches) drifts slowly eastward over the northern half of the peninsula. Sluggishness is at times a characteristic of these "highs," vide March 9-10 of the current year, and when such conditions obtain the strong outward radiation results in temperatures of 15° to 20° below the seasonal average with frost southward to the prairies of the Everglades.

Paradoxical as it may seem, there are times when moderate damage from frost is not an unmixed evil. Mild winters (practically without decided damage to crops on the immediate Gulf and the south Atlantic coast sections) enable producing districts to the north and west to realize maximum crop yields. As a consequence of the favorable weather conditions there is overproduction—the concomitant of low prices. It is generally recognized that moderately cold winters (which result in retarded growth and more or less limited production) are conditions favorable to the Florida grower, so far as his vegetable crop is concerned. A corollary is seen in cotton production—a moderate crop being more remunerative to the farmer than a large crop, that may be in excess of current demands.

Methods for protecting crops from frosts vary with the kind of crop, its location, the period of frost occurrence, and the degree of cold expected. Lettuce, cabbage, and celery withstand quite low temperatures without serious damage, except at certain periods of growth. So, too, the strawberry, except at the time of bloom, or when the fruit has set, when a heavy frost results in damage. The most general method of protection is by covering plants with grass or straw. Some "truckers" have a system of subirrigation and others have surface irrigation. During periods of danger the various local ditches for drainage are easily flooded with warm artesian water, the temperature of which is from 60° to 70°. This process raises the temperature of the dew point and adds heat to the air, generally with happy results for the crop. The effectiveness of this method is somewhat impaired by high winds. Some plants are covered with dirt—"plowed under"—provided the plants are not too advanced; this method is effective with young tomatoes and Irish potatoes. Sugar cane is "windrowed."

The methods of protecting citrus trees and fruit multiplied after the cold waves of recent decades. Fundamentally, however, that of dry heat—raising the temperature of the lower layers of air—still predominates. Wood fires are built throughout the grove, preparation being made in advance by distributing cordwood in the centers of the squares. The wood is ignited when the temperature in thermometer shelters falls to about 26° or 28°, particularly if the tendency of the temperature is downward. During calm nights the temperature can be raised by 4° or 6° F. Should freezing weather be attended by high winds, the method is not so satisfactory, as the wind carries the heat from the grove. Succeeding the disastrous cold waves of 1894 and 1899, some groves were protected by sheds, which were simply a flat top of boards supported by posts. This provision retarded radiation, and, if the temperature fell dangerously low, the heat was increased by placing heaters throughout the grove. The method, while feasible and very effective, is expensive, and it is now more or less obsolete. The use of heaters is probably the most satisfactory plan at this present time. Various kinds of heaters are manufactured, and their use has been attended with success. Fuel oil of a low grade is used in the heaters with increasing favor. Irrigation of groves and the spraying of trees with artesian water have proven very helpful.

The low temperatures of winter, involving the safety of the citrus fruit, and the late frosts of spring which have to do with citrus bloom and vegetables, are discordant factors in the harmony of the grower's life. Action to negative the effects of damage from cold is recognized and, by many, is methodically carried out. There are,

however, some who submit to the law of chance, and as a sequence they often reap the reward of the improvident. Long immunity from severe cold spells begets an optimism that spells financial disaster to the grower who yields to its seductive influence.

XII.

FROST PROTECTION IN ARIZONA.

By ROBERT R. BRIGGS, Section Director.

[Dated Weather Bureau, Phoenix, Ariz., Nov. 29, 1914.]

At present, except in a relatively small portion of the State, a special study of frost conditions, or the early advance information of the probable occurrence of frost or freezing temperature can serve no important interests in Arizona, for the reason that no protective measures are practicable for such agricultural products as are grown in marketable quantities. Only such observations of temperatures and frosts as may determine the average dates of killing frosts in spring and autumn, the length of the growing season, and the most favorable times for planting and harvesting various crops can be of advantage to most localities. Apples, peaches, and other fruits ordinarily grown in temperate climates can be produced in many of the valleys of the northern half of the State and of the eastern and southeastern counties of Arizona. Up to the present time such orchards have been principally confined to the small amounts needed for the personal use of the grower. In the high valleys of Yavapai County, near Prescott, apples have begun to be grown to a considerable extent for market, and with such success in yield and quality that the orchard acreage is increasing rapidly.

The only danger of damage from freezing lies in the possible occurrence of a decided cold spell after the buds are well along in the spring. Growers have to some extent provided themselves with fire pots for artificial protection. As many of the orchards are isolated and without telephone facilities, dependence is placed chiefly upon alarm thermometers and observations of local weather conditions, although the Weather Bureau furnishes warnings to Prescott for distribution to such growers as can be quickly reached. In the Verde Valley, in the eastern portion of Yavapai County, not only apples but peaches, apricots, and other fruits are grown in marketable quantities, but here the elevation is more moderate and injurious frosts seldom occur during the growing season.

This reduces the area in which a special study of temperature conditions is important for the introduction, culture, and protection of crops susceptible to injury from frost. The temperature of the southwestern lowland counties is generally favorable for the production of semitropical fruits and staples.

There is relatively but a limited portion of the lowland counties now under cultivation, owing to deficient rainfall and the impossibility as yet of economically supplying water artificially. The Salt River Valley lands, under the Roosevelt Project, is the most important section yet reclaimed both in extent of acreage and in diversity of products. What may be said of the importance of frost study and of frost protection to that section will apply largely to other sections of the lowland districts where reclamation has been effected or may be possible in the future. The Salt River Valley is typical of the topography of the entire southwestern portion of the State. It lies between two short ranges of low, barren mountains, sloping gently from the foothills north and south to the river between.

In the colder months there is a considerable range in the Salt River Valley between the night or early morning temperatures of the higher slopes and those of the low bottom lands, amounting frequently to from 10° to 15°. This difference is so marked that in many seasons such tender plants as tomatoes and castor beans remain green on the higher slopes throughout the winter, while in the low sections they are killed in November or in early December. Citrus fruits can be grown without extreme hazard, but only in the sections having the most favorable temperature. For olives the possible acreage is considerably greater, as the trees are hardier than citrus, except when very young. Recent experiments with sugar cane seem to indicate that it can be grown successfully upon both the higher and the intermediate lands, while cotton is grown indiscriminately throughout the valley. Nearly all fruits, except apples, as well as most staples, except corn, are grown here more or less extensively, but protective measures during critical cold spells and the consideration of the relative temperature conditions of various areas are matters of first importance to citrus and olive culture.

The possible revenue from oranges, grapefruit, and ripe olives is greater than from other products; hence the lands upon which they can be grown must necessarily become more valuable than lands that are unsuitable. As the deciding factor is mainly that of temperature, one realizes the importance of an investigation into the determination of the line of demarcation beyond which it would be too hazardous to attempt their culture, even with provision for artificial protection. By an extensive distribution of recording instruments, extending on each side of the Salt River Valley from the bottom lands to the higher slopes, the Weather Bureau is now carrying on such an investigation, primarily to determine the extent of the acreage that may profitably be devoted to citrus and olives, and secondarily to gain a better knowledge of the temperature of the entire area under cultivation. If the relative temperature were dependent upon difference in elevation alone, it would be a simple matter to define the favorable areas, but proximity to the bare rocks of the mountain sides, receiving and storing heat during the daytime, and the air drainage at night, as affected by gaps in the ranges or by the gradient of the slopes, are complicating factors.

Growers are coming more generally to realize the advantage of artificial protection from frost. Practically no protective measures have been employed here until in recent years, but, while there are many old orange groves now bearing abundantly that have never received artificial protection, it is recognized that others have been killed that might undoubtedly have been successfully protected, and that without such protection the entire profitable area for the culture can not be utilized. Measures are now taken to protect nursery stock, and young orchards during the first two seasons, with cylindrical tubes filled with dry earth and by other devices, while older groves are variously protected by fire pots and by spraying. The fruit ripens early and can be mostly marketed before damaging cold spells are probable, with the advantage that in the event of freezing weather the trees alone remain to be cared for The Weather Bureau is not only taking every precaution to give warning of the approach of dangerous cold spells, but it is also urging the growers, as an additional precaution, to install alarm thermometers or to take

other measures to observe any sudden fall in temperature approaching the danger point. With better protective facilities and a better knowledge of the requirements for successful culture confidence is increasing, resulting at present in a phenomenal extension of the acreage in young groves.

XIII.

FROSTS AND FROST PROTECTION IN TEXAS.

By MALCOLM SPRAGUE, Observer and Acting Section Director.

[Dated Weather Bureau, Houston, Tex., Nov. 30, 1914.]

In considering the subject of frosts and frost protection in Texas, the great diversity of climatic conditions which exist within the limits of the State must be referred to.

In the coast section, which borders the Gulf of Mexico for a distance of 350 miles, climatic conditions are largely influenced by the warm waters of the Gulf. The winters are mild and short, the annual and diurnal ranges of temperature are small, and cold spells are followed by extended periods of damp, foggy weather. The cold periods are of short duration and are rarely severe enough to kill the more hardy vegetation. Truck growing is most profitably carried on during the winter months, and large areas are devoted to sugar cane, strawberries, and citrus fruits. In this coastal section an unexpected freeze causes immense loss and the growers are prepared to protect their crops. Strawberries and truck are injured by frosts, but sugar cane and citrus fruits will withstand a temperature several degrees below freezing.

In central and northern Texas there are some orchards, but, so far as known, little effort has been made to protect from injury by frost. Not much farming is done in this part of the State during the winter months. Corn, cotton, and small grain are the principal crops. A late frost in spring kills early planted corn and cotton, but the area devoted to these crops is so large that no protection can be given. Late cotton and the "top crop" are sometimes killed by unusually early frosts in autumn. Warnings of severe weather conditions are of great value to shippers and stockmen in this section, but are not so much used by farmers.

East Texas is wooded, and the climate is moist and well adapted to small fruits and early spring truck. There are large commercial peach orchards and tomato farms in this section. A late frost in spring may destroy the peach crop and delay the tomatoes so that they will reach northern markets too late to be sold at a profit. Many of the growers have made arrangements to protect against frosts and freezes; warnings are of greatest value from the middle of February throughout the spring months.

In west Texas and the panhandle the climate is continental in character, with hot summers and cold winters, and the cold waves are more frequent and severe. Stock raising and the growing of small grain are the principal industries. Commercial orchards are being developed in the Rio Pecos Valley and in portions of the panhandle, resulting in an increasing demand for frost and cold-wave warnings. Frost warnings are of greatest value after March 1; warnings of cold waves are needed by stockmen throughout the winter.

In extreme northwest Texas the first killing frost of autumn usually occurs during the last decade of October, but has been recorded as early as September 26. The last killing frost in spring usually occurs in April, but has been recorded as late as May 7.

In going southeastward the growing season gradually lengthens, until in the lower coast section the average date of the first killing frost in autumn is late in December and of the last killing frost in spring early in February; but there have been winters without freezing temperatures. On account of the high winds and dry air that attend the cold waves that reach the coast, freezing temperatures are more frequent in this section than killing frosts.

Frosts in Texas rarely occur on the first morning of a cold wave, but are probable on the second and third mornings if the temperatures continue low and the winds become light. They occur at a higher temperature in east Texas and the coast section than in central and west Texas.

It is only recently that systematic efforts have been made to protect crops from cold waves and freezes. In the peach orchards and trucking districts of east Texas orchard heaters and smudge pots have been used to some extent with satisfactory results. The cane grower, upon receipt of warnings, cuts and windrows his cane, which would have been a total loss if allowed to freeze before cutting. Strawberries are usually protected by covering with a mulch of straw or hay which had been placed between the rows for this emergency. Between the cold spells the covering is removed. By using this precaution strawberries are marketed from the Houston-Galveston district from late in December to June 1.

In the trucking and citrus fruit district of south Texas smudge pots and heaters are used by many growers, while others build fires to the windward side of their fields. The great drawback in the use of artificial heat is the high wind that attends the Texas cold wave or "norther" during the first 12 to 36 hours after its arrival. It rapidly carries the smudge or heat beyond the limits of the area to be protected. To overcome this difficulty windbreaks are being planted in some sections. The smudge pots and heaters are effective, however, on the second or third night of the cold spells, when the wind has fallen and conditions are favorable for frost formation. Among other methods of protection against freezes are the covering of plants with soil and spraying and flooding. Flooding is found to be most efficient in the irrigated districts.

While the weather forecasts are published daily in the press and distributed by mail, telegraph, and telephone to our urban population, they formerly reached only a small percentage of the rural communities in time to be of benefit. Since the cooperation of the telephone companies of this State with the Weather Bureau, however, frost and cold-wave warnings are available to nearly every farmer, and the matter of protection is receiving increasing attention from the fruit and trucking interests. South Texas has a great future as a citrus fruit and winter truck-growing district, but to make these industries stable greater precautions must be taken to prevent the loss of a season's work by a frost or freeze.

XIV.

FROST PROTECTION BY IRRIGATION IN SOUTHERN TEXAS.

By JOSEPH L. CLINE, Local Forecaster.

[Dated: Weather Bureau, Dallas, Tex., Nov. 25, 1914.]

The cultivation of vegetables for the winter and early spring markets has been carried on over southern Texas to some extent for many years, but since large irrigation plants have been put in operation, this industry has, in the last 10 years, been so extended that many farmers now devote their entire time to truck raising. Occasionally in severe winters vegetables that are not protected from killing frosts and freezing temperatures are badly damaged or destroyed.

Many methods of protecting crops from frost and injurious temperatures have been tried over southern Texas. Some methods, used elsewhere to advantage, have proven too expensive in this section of the country. Smudging by pot-fires, so highly praised in other sections of the United States and some foreign countries, is very expensive and has not proven a success in portions of southern Texas, because the brisk to high winds that generally accompany cold waves and freezing temperatures carry the smoke and heat away from the crops; however, this method is very beneficial in calm weather.

On account of the prevailing local conditions, a covering with hay or cloth, or flooding the land with water where possible, have proven to be the most successful and least expensive methods of protecting small crops in southern Texas from frost or injurious temperatures.

Frost never forms unless the condensation of the aqueous vapor in the atmosphere takes place with temperatures at, or below, the freezing point. Plants lose their heat principally by radiation and convection; this takes place more rapidly in some localities than others, depending somewhat upon the character and condition of the soil, the topography of the country, and the degree of cloudiness. Any method of preventing the radiation and convection of heat from plants during unusually cold weather will prove beneficial in protecting crops. The spraying of plants and trees with a fine spray of water on a frosty morning before sunrise is beneficial. Apparently this water is absorbed by the outside cells of the frozen plants and buds of the trees as they thaw, thus preventing the bursting of the cells and the disorganization of the plant tissues so that the damage by the freeze is greatly reduced.

During the winter of 1904–5 the writer observed the effects of a severe freeze on cabbage in the vicinity of Corpus Christi, Tex. The cabbage heads were about 8 inches in diameter when a cold wave with a minimum temperature of 18°F. was experienced. The heads were frozen through, there being ice at the center. The sky remained cloudy during the cold wave, and when the temperature rose above freezing a light rain commenced falling. The plants thawed out slowly and where earth was thrown up so as to cover the stalk, the cabbage almost fully recovered from the effects of the freeze. Where the stalk was not hilled or covered with dirt it became diseased in the center and soon decayed, withered and fell, making it necessary to immediately gather these plants for use, before the disintegration extended from the stalk into the cabbage head. These cabbages were large enough for the market at that time. Those plants that had earth around the stalks continued to grow and in a short time showed practically no serious effects of the freeze.

At other times when in Weather Bureau shelters temperatures of 22° to 28°F. were experienced with a clear sky, it was observed that soon after the sun commenced shining and the temperature rose above freezing cabbage and other vegetables were damaged and small plants occasionally killed, but when it rained as the temperature rose to freezing or above, the damage to truck was generally slight if any.

When irrigation was put into operation the truck gardeners near Corpus Christi, Tex., who were prepared to irrigate were advised to flood their fields when killing frosts or freezing temperatures were expected. A number of the truck growers made arrangements to get the forecasts over the long-distance telephone at their own expense when freezing weather was forecasted. They depended upon the advice of the Weather Bureau official who telephoned the warnings as to the necessity of flooding their fields. They also observed from actual experience that when cabbage and other hardy vegetables were flooded with water during periods of freezing temperature, then their crops, though sometimes damaged, could generally be saved during the coldest weather experienced in that section of the country. Even when ice formed around the plants, especially cabbage, these appeared to thaw out gradually. The plant cells were generally left in normal condition and the crops would continue to grow after the plants and cabbage heads had been frozen.

Another advantage resulting from the protection of vegetables by flooding in southern Texas is that since the earth is always warm prior to the approach of the cold waves, hence the water being warmed by conduction from below cools slowly, and as a result the air surrounding plants that are flooded is not quite so cold as in fields which are not flooded with water.

Cold waves over southern Texas rarely last more than one or two days. Owing to the short duration of freezing temperatures, cabbage and other hardy vegetables have not thus far been damaged by the water remaining on the fields where drainage is well provided. When tender plants are left under water several days they will not recover from the effects of being flooded, hence fields should never be flooded until near the approach of injurious temperatures. As soon as the air temperature rises above freezing the fields should be drained to prevent damage to plants from being under water too long. Cabbage and other garden truck, where raised in the winter months, should be cultivated so that the stalks will be covered with dirt if possible. This makes a ridge or hill around the plants, protecting them to some extent from the cold. When so cultivated it is an aid to quick drainage and recovery from the effects of flooding, as the first soil to be drained is that which immediately surrounds the plants.

When the results obtained by flooding crops during freezing weather are compared with the lowest temperatures experienced, the value of protection of crops by irrigation can be ascertained. To enable such a comparison, tables showing the lowest temperatures over southern Texas, with remarks of truck growers who saved their crops by protection, are here given.

The following table shows the monthly and annual minimum, or lowest, temperatures in degrees (Fahren-

heit) at Corpus Christi, Tex., since the station was established, February 1, 1887, to 1913, inclusive:

TABLE 1.

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1887	....	33	46	46	57	70	72	72	59	**49**	33	24	....
1888	**16**	43	41	57	**44**	66	73	71	63	50	39	37	16
1889	34	42	45	58	56	69	74	70	56	54	40	46	34
1890	32	30	**28**	50	58	65	70	74	55	50	42	35	28
1891	33	34	37	46	64	64	70	**65**	66	51	34	36	33
1892	25	48	31	49	60	64	72	71	65	45	42	27	25
1893	34	33	41	56	57	70	73	69	70	53	40	36	33
1894	24	29	38	58	63	64	70	70	67	**42**	42	26	24
1895	32	16	38	51	58	70	76	73	62	53	38	28	16
1896	34	39	42	53	65	68	72	70	58	56	30	32	30
1897	22	32	47	52	60	65	72	73	58	55	43	29	22
1898	36	41	40	51	58	64	72	74	69	47	38	28	28
1899	28	**11**	42	**44**	66	71	75	75	65	55	41	36	**11**
1900	29	29	41	47	61	70	72	72	75	54	38	38	29
1901	32	33	42	52	60	67	74	74	60	62	48	**20**	20
1902	28	35	44	53	63	72	76	73	61	59	41	36	28
1903	35	27	42	52	51	**59**	68	70	54	50	37	39	27
1904	29	32	38	50	61	68	70	73	70	52	37	33	29
1905	26	18	48	49	63	70	**65**	73	70	48	46	32	18
1906	30	30	37	53	58	68	72	71	68	52	33	36	30
1907	36	38	48	47	47	65	71	73	67	61	37	**44**	36
1908	35	38	48	48	53	74	68	70	**53**	48	39	40	35
1909	24	27	41	48	56	69	75	73	54	53	46	30	24
1910	30	26	48	54	61	68	73	73	70	48	48	44	26
1911	21	37	45	55	57	72	71	73	72	47	**29**	35	21
1912	22	25	40	53	60	65	74	75	61	54	39	36	22
1913	27	35	37	48	63	71	72	74	59	45	46	41	27

The following table gives the monthly and annual minimum, or lowest, temperatures at Fort Brown or Brownsville, Tex., from November 1, 1892, to 1913, inclusive, except during months when no records were kept:

TABLE 2.

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1892	....	....	....	....	....	....	....	....	....	....	42	**29**	....
1893	27	33	42	....	50	62	70	65	67	52	44	33	....
1894	31	27	39	57	64	64	63	69	66	44	46	27	27
1895	32	22	39	48	**41**	59	**57**	**63**	69	56	40	32	22
1896	38	35	40	45	67	66	65	63	51	56	30	....	....
1897	....	....	....	....	....	....	....	67	59	50	43	30	....
1898	....	....	....	....	....	....	....	....	....	....	....	....	....
1899	32	**12**	45	46	69	67	71	73	60	**38**	....	....	**12**
1900	....	27	40	47	64	71	65	71	63	48	37	**25**	....
1901	....	....	....	....	....	60	....	68	58	53	....	....	....
1902	....	29	40	52	66	70	70	72	63	56	38	35	....
1903	37	26	38	**37**	51	**59**	73	73	64	50	40	40	26
1904	32	36	41	51	58	68	69	67	71	50	41	39	32
1905	30	22	48	54	63	68	68	72	68	52	51	33	22
1906	30	32	40	58	61	69	70	72	....	....	....	....	....
1907	....	....	....	....	....	....	....	70	68	59	36	40	....
1908	35	35	46	49	59	72	68	69	58	46	40	38	35
1909	28	29	40	46	61	67	72	71	**51**	53	54	33	28
1910	30	32	46	46	58	64	71	70	69	44	42	37	30
1911	**21**	38	49	57	58	68	70	69	71	44	**27**	34	21
1912	24	27	40	52	56	64	71	70	63	53	39	34	24
1913	30	37	**33**	44	55	65	69	70	56	45	44	34	30

The following statement is by Mr. Charles E. Coleman, of Corpus Christi, Tex., one of the leading vegetable growers and heaviest shippers of produce by express in southwest Texas, relative to protection of cabbage from freezing temperatures by flooding. Mr. Coleman says:

During the winter of 1910–11, I purchased in the field near Corpus Christi some 60 acres of growing cabbage, all under irrigation. A few days after purchasing these crops and while you were with the United States Weather Bureau at this point you advised me one evening that a cold wave would reach Corpus Christi the following day, and advised me to flood my cabbage fields with water from our irrigation ditches. I immediately telephoned my men and had them flood the fields, as suggested, and, as a result, the growing cabbage was very little damaged, although the thermometer went as low as 17°F., which was unusually cold for this section of the country.

As a result of our saving our cabbage, it was sold at a good price, while cabbage growing in other fields that were not irrigated suffered very severely from the freeze, and in a great many instances was entirely killed, thereby entailing a heavy loss upon the grower.

I would have sustained the same loss in my crops had not you advised me promptly of the coming cold wave, and for this reason we are warm advocates of the Government system of weather warnings.

Mr. C. H. Pease, a prominent citizen of Raymondville, Tex., who has used heaters burning crude oil for the protection of orange trees only, says:

During the winter of 1911–12, I used heaters in a small orchard of oranges. The freeze on Thanksgiving was the first time that I used them. The trees heated did not drop a leaf, while those adjoining that were not protected lost all of their leaves and were frozen back. The second week in January, 1912, I again heated one night, with the result that the trees did not drop a leaf, while those not protected were frozen to the ground. The protected trees bore lightly during the season of 1912, and in 1913 they bore heavily, yielding two boxes excellent fruit to the tree. Those unprotected that froze to the ground came up, as they were banked with earth, and this year, 1914, they are also heavily loaded with fruit. The heated trees were planted thickly, about 200 to the acre. I used crude oil burners, one pan to the tree. I had a thermometer in the center of one of the trees, and it never fell below 28° during the night. No frost formed on the trees. Outside of the protected area a thermometer registered 19°F. The night was calm, making it unusually favorable for this method of protection. With a high wind, I believe a wind break with wood fires on the north, would supplement the oil fires.

Mr. M. L. Gilliland, of this place, covered an acre of watermelons with a conical frost protector and saved them from a late frost. From this acre he loaded the first car of watermelons in this place, and received $336 for the carload. He had some 15 acres that were not protected, and from them he sold $900 worth of melons. The acre protected yielded him about five times as much revenue per acre as the land not covered.

A large number of farmers are investing in these protectors, preparatory to planting watermelons early next spring.

Mr. Marcus Philips, a leading citizen of Riviera, Tex., in writing of protection of citrus fruit trees says:

The forecasts of frost and freezing temperatures that I received from the United States Weather Bureau for several years, through you at Corpus Christi, Tex., were of great value as shown by the results of fruit trees protected.

Citrus fruit trees at Riviera were protected by the use of canvas and a small lantern. The canvas was made like a wagon cover, but long enough to reach around the tree, was drawn together at the top and bottom, and the lighted lantern placed inside at the base of the tree. This afforded absolute protection and did no damage. The lowest temperature recorded was 16°F., on February 18, 1910.

Citrus trees were also protected by covering with covered boxes and filling the spaces between the foliage and branches in the boxes with loose hay. This was also effective.

Nearly all the unprotected citrus trees during temperatures of 20° or lower. were severely injured or killed.

Very little protection was given to vegetables in this locality. In a few instances watermelons and beets were plowed, drawing the dirt very close and almost covering the plants, which usually saved a large per cent of the crop.

SECTION III.—FORECASTS.

STORMS AND WARNINGS FOR OCTOBER.

By H. C. Frankenfield, Professor and District Forecaster.

[Dated Washington, Nov. 11, 1914.]

While there were no severe storms during the month there were a number of disturbances of more or less marked character that required warnings, the great majority of which, however, were small-craft warnings, and of the storm warnings ordered by far the greater portion was for the north Pacific coast.

On the 1st day of the month pressure was falling rapidly over the extreme north Pacific coast and during the afternoon and evening southeast and southwest storm warnings were ordered generally on the Washington and Oregon coasts. The storm moved rapidly into the interior with decreasing intensity and no high winds were reported after the evening of the 1st. Consequently warnings were ordered down on the morning of the 2d. At this time also there was a moderate disturbance over the Gulf of Mexico with a marked high pressure area over eastern New York. Small-craft warnings were therefore ordered at 10 a. m. from Savannah, Ga., to Norfolk, Va., and fresh to moderately strong winds occurred during the day. At 8 p. m. of the 2d the Gulf disturbance appeared to be a little more threatening and storm warnings were ordered at 9:30 p. m. from Savannah, Ga., to Fort Monroe, Va. There was no further development, however, and on the morning of the 3d the warnings were ordered down. There were still some evidences of the disturbance over the northern Gulf of Mexico, and small-craft warnings to this effect were issued. On the morning of the 4th there was a tropical disturbance near the mouth of the Yucatan Channel, accompanied by heavy rains but without winds of consequence, and advisory messages to this effect were at once sent to all coast stations between Boston and New Orleans. The disturbance did not develop materially and no further advices were necessary. During the 4th a well-marked disturbance from the northwest extended from North Dakota to eastern Colorado, and at 2 p. m. small-craft warnings for fresh to strong winds were ordered on Lake Superior from Duluth to Marquette, and on Lake Michigan at Escanaba and Green Bay. The disturbance rapidly disintegrated during the afternoon of the 4th and the warning was not justified. On the morning of the 6th there was a moderate depression some distance off the North Carolina coast with marked high pressure to the northward and small-craft warnings were therefore ordered for the extreme southern New England coast. These were followed by fresh to strong northeast winds.

On the morning of the 10th a middle Plateau disturbance of considerable energy had reached northern Illinois and small-craft warnings were ordered for the Lower Lakes. The disturbance moved northeastward to upper Michigan during the afternoon of the 10th and small-craft warnings on the Lower Lakes were fully justified. There were also some moderately strong winds on the Upper Lakes, but not sufficient to justify warnings for west winds. On the morning of the 12th the entire western interior of the country was covered by an extensive area of high pressure with falling pressure near the mouth of the Rio Grande, and small-craft warnings were ordered on the Texas coast. The winds, however, did not attain more than a moderate velocity. On the same morning (12th) a disturbance was approaching the north Pacific coast, and at 7:15 a. m. southeast storm warnings were ordered on the northern Washington coast. No high winds occurred and on the morning of the 13th the warnings were changed to small craft and extended southward to the mouth of the Columbia River. On the morning of the 13th small-craft warnings were also ordered along the lower Lakes and the Atlantic coast from Norfolk, Va. to Nantucket, Mass., for the strong northeasterly winds that occurred during the day from a moderate depression over the Ohio Valley and a strong high area over Ontario. During the 15th a moderate depression moved into British Columbia from the Pacific Ocean and southwest storm warnings were ordered at 6:40 p. m. for the north Washington coast. Only moderately high winds occurred and on the following morning the warnings were changed to small craft and extended southward along the Oregon coast. On the 16th, however, there was a pronounced disturbance off the extreme north Pacific coast and southeast and southwest storm warnings were ordered during the morning from Cape Mendocino, Cal., northward. This disturbance caused high winds, as forecast, with a maximum velocity of 74 miles an hour from the southeast at North Head, Wash., during the 16th. During the 17th there was a redevelopment on the extreme north Pacific coast and at 6:40 p. m. southwest storm warnings were continued on the north Washington coast and extended southward to the mouth of the Columbia River. As the disturbance continued to develop warnings were further extended on the morning of the 18th to Cape Mendocino, Cal., and continued again at night from the mouth of the Columbia River northward. Severe gales resulted from this disturbance, the wind velocities on the Washington coast ranging from 60 to 76 miles an hour from the southeast and south. On the morning of the 19th the storm center passed into the interior and the warnings from the mouth of the Columbia River northward were changed to small-craft. At this time a moderate disturbance from the interior had reached southern New England, with fairly high pressure to the northeastward, and at 2 p. m. northeast storm warnings were ordered for the eastern Maine coast. A moderate, though very brief, northeast gale occurred during the afternoon and the warnings were lowered at 9 p. m.

On the morning of the 23d abnormally high pressure prevailed over New England, and moderately low pressure over the Gulf of Mexico, indicating the probability of strong northeast winds along the Atlantic coast and small-craft warnings were therefore ordered at 10 a. m. from Norfolk to Nantucket. There was also a moderate disturbance to the northward of Lake Superior and small-craft warnings were also ordered from Duluth to Marquette. Strong west to northwest winds prevailed

on Lake Superior, but along the Atlantic coast they were not more than fresh, although a short distance off the coast radio reports indicated strong easterly winds. Pressure had now been low for several days over the southern Gulf of Mexico and as there was a strong high pressure area to the northwestward, small-craft warnings were ordered on the morning of the 24th for the entire Gulf coast between the mouth of the Rio Grande and Carrabelle, Fla. Owing to the local situation small-craft warnings were also ordered at 11 a. m. on Lake Huron from Saginaw to Port Huron. During the 24th the Gulf disturbance appeared to develop somewhat, especially near the mouth of the Rio Grande, and northeast storm warnings were ordered at 10 p. m. for the Texas coast, and orders also issued to hoist small-craft warnings on the following morning eastward to Carrabelle, Fla. On the morning of the 25th there were evidences of quite marked development in the Gulf disturbance with its center apparently near the Yucatan Channel. The official in charge at Galveston, Tex., reported a high tide and rough sea, and storm warnings were therefore continued eastward so as to include the districts as far as Apalachicola, Fla. There were also indications of the development of a secondary disturbance off the North Carolina coast and small-craft warnings were therefore ordered from Norfolk to Nantucket; advisory messages were also sent to all display stations on the Florida coast between Carrabelle and Miami. The Gulf disturbance did not develop to any great extent, and it finally turned to the northeastward, passing over central Florida during the 26th. On the morning of the 27th it was central about 400 miles east of the Florida coast and from thence continued northeastward, passing the island of Bermuda in very moderate form during the night of the 27th. On the morning of the 26th a Canadian Northwest disturbance had reached the St. Lawrence Valley with fair development and was followed by a strong and cold high area. There were some moderately strong westerly winds on the Great Lakes, but none sufficient to justify warnings, except in the vicinity of Cleveland, Ohio, where the winds locally reached a velocity of 52 miles an hour from the north. A small-craft warning had been issued at this station during the morning of the 26th. Northwest storm warnings were ordered at 3:30 p. m. for the Lower Lakes, but they failed of verification. Another Canadian Northwest disturbance reached northern Lake Superior during the 27th with strong high pressure to the southward, and southwest storm warnings were ordered at 3:30 p. m. for Lake Superior and the northern portions of Lakes Michigan and Huron. Moderately strong winds occurred during the night of the 27th, but none of gale force, and at 9 a. m. of the 28th the warnings were ordered down. Small-craft warnings were ordered, however, at this time for the lower Lakes and strong southwest winds occurred during the day. On the morning of the 30th low pressure again prevailed off the north Pacific coast and small-craft warnings were ordered on the Washington and Oregon coasts, except at Marshfield, Oreg. Small-craft warnings were also ordered at New York City for the strong local northwest winds that occurred during the day following the passage of a moderately low area to the northward. There was at this time another Canadian Northwest disturbance moving eastward and by the morning of the 31st it was central north of Manitoba in quite well defined character with a strong and cold high area to the southeastward. Small-craft warnings were therefore ordered in the morning for the northern portion of the upper Lake region, and in the evening for the lower Lake region and southern Lake Huron.

FROSTS AND WARNINGS.

Frosts were quite numerous during the month, and, unless otherwise indicated, it will be assumed here that they occurred as forecast.

On the 3d the barometer was quite low over the adjacent portions of Colorado, New Mexico, Utah, and Arizona with rising pressure to the northwestward, and freezing temperatures were forecast for the following morning over the high districts of New Mexico and Utah. Frosts were also forecast for northern and western Montana, and temperatures close to the freezing point with rain and snow occurred. On the morning of the 4th with marked low pressure prevailing in the Slope region, heavy frosts were forecast generally for Utah and west Colorado, and heavy frosts or freezing temperatures for east Colorado, Wyoming, west Nebraska, west Kansas and the Northwest generally. On the morning of the 5th light frost occurred as far south as Dodge City, Kans. On the morning of the 6th high pressure prevailed generally over the eastern portion of the country and frost warnings were issued for northern New England. This forecast was verified except along the immediate coast. On the 10th warnings of frost or freezing temperatures were issued for North Dakoto, and frost warnings for the western upper Lake region, Iowa, Nebraska and northwestern Missouri. These warnings were not verified, owing to a rapid pressure fall over the central Rocky Mountain region. On the morning of the 11th the western disturbance had reached central Ontario and frost warnings were issued for eastern North Dakota, Minnesota, and low places in Wisconsin, and also for Michigan, north Indiana, north and central Ohio, and west Pennsylvania. These warnings also failed, owing to the rapid eastward movement of the western disturbance. This western disturbance was now central over Iowa and was followed by cold high pressure. Frost warnings were therefore issued on the 12th for Colorado, Kansas, Nebraska, Iowa, northwest Missouri, and the Texas panhandle, and warnings of frost or freezing temperatures for the Dakotas and Minnesota. These warnings were not verified east of the Missouri River, except in North Dakota, as on the morning of the 13th the disturbance persisted over the Ohio and upper Mississippi Valleys. At this time frost warnings were again issued for the Dakotas, west Minnesota, Kansas, west Missouri, Arkansas, Oklahoma, northwest Texas, and eastern New Mexico. On the morning of the 14th the disturbance still persisted over the Ohio Valley, though in very moderate form, and there were no frosts south of northern Nebraska, except in the Texas panhandle. Frosts also occurred in upper Michigan for which no warnings has been ordered, it having been assumed that cloudy weather would continue with the low area to the southward. Frosts were now forecast for eastern New Mexico, northwest Texas, the extreme north portion of east Texas, Oklahoma, northwest Arkansas, west Tennessee, northern Wisconsin, Michigan, Minnesota, Kansas, Nebraska, and extreme western Iowa. Owing to the persistence of the southern disturbance with the attendant cloudy and rainy weather these warnings also failed of verification, except in portions of Minnesota, Kansas, New Mexico, and adjacent portions of Iowa and South Dakota. On the morning of the 15th frost warnings were ordered for Minnesota, Nebraska, northwest Wisconsin, and northwest Iowa with good results. Similar warnings, however, for western Oklahoma and the north portion of west Texas were not justified. On the 16th frost warnings were issued for Nebraska, Kansas, and northwest Iowa, and on the 17th for west and central Iowa

and North Dakota and western Wisconsin, those of the 17th failing of verification.

On the morning of the 22d pressure was low over the western portion of the Dakotas and in the central Rocky Mountain region with rapidly rising pressure to the northwestward, and frost warnings were ordered for northwest Colorado. Although pressure was abnormally high to the northward, temperatures did not fall materially and the forecast failed. On the morning of the 23d pressure was moderately low from northwest Iowa to western Lake Superior and abnormally high to the westward, and warnings of frost and freezing temperatures were therefore issued for northern and western Minnesota, and warnings of frost for eastern New Mexico, the latter failing of verification owing to rain. On the morning of the 24th the northwest high area had increased somewhat in intensity and there was only a moderate low area over the extreme Northeast; frost warnings were therefore issued for Nebraska, northern and western Kansas, eastern New Mexico, the Texas panhandle, western Oklahoma, northern Iowa, Wisconsin, Minnesota, and Michigan, with excellent results from the forecast standpoint. On the morning of the 25th low pressure prevailed along the Middle and South Atlantic coasts, over the Gulf of Mexico and to the northward of Lake Superior with high pressure over the central West, and frost warnings were ordered for the central West, the Ohio Valley, and the Lake region generally. Freezing temperatures occurred in the Lake region and extreme upper Mississippi Valley on the following morning, but there were no frosts to the southward. On the 26th another strong high-pressure area had reached to the Dakotas and there was a well-defined low area over the St. Lawrence Valley. Frost warnings were then issued for the Southwest, the central West, the Ohio Valley, the Lake region, and the Middle Atlantic States. These forecasts were followed by heavy to killing frosts and freezing temperatures, except in New Jersey, Maryland, and southern portions of eastern Pennsylvania. On the morning of the 27th, with the tropical disturbance off the Florida coast and strong, cold high pressure over the interior of the country, general frost warnings were issued for the entire East and South, as far south as northern Florida, and on the morning of the 28th frost occurred to the east Gulf coast. Another warning was issued on the 28th for the frosts that occurred on the morning of the 29th in Georgia and South Carolina.

SECTION IV.—RIVERS AND FLOODS.

RIVERS AND FLOODS, OCTOBER, 1914.

By ALFRED J. HENRY, Professor of Meteorology, in charge of River and Flood Division.

[Dated Washington, D. C., Dec. 1, 1914.]

The precipitation of the month was not sufficiently heavy or prolonged in any one region to produce severe floods in the streams. There were, however, a few cases of heavy and continued rains that resulted in destructive floods. Perhaps the most severe of these purely local floods was the one that occurred on the 23d in Alazan and San Pedro Creeks, tributaries of the San Antonia River, which join that river in the town of the same name in Texas. The overflow swept the valley clear of outhouses and the frail dwellings occupied by the poorer classes. Nine persons were drowned and the property loss is estimated at $45,000.

A very sudden rise, estimated at 30 feet, occurred in the Rio Grande, at Del Rio, Tex., on the 21st; the crest of this flood passed Eagle Pass, Tex., on the 22d; Laredo on the 24th; Riogrande, Tex., on the 25th; and Mission on the 27th. The damage from this flood was confined mostly to crops and property that could not be removed from the river. The total loss is estimated at $16,000.

The precipitation which caused the above-described flood was not recorded at Weather Bureau stations in the Rio Grande Valley, although there was a general fall of rain in the State on the 23d, 24th, and 25th, west of the ninety-fifth meridian.

These rains caused a rise of approximately 20 feet in the Guadalupe River from the 23d to the 25th. In the lower part of Victoria County, Tex., the river overflowed its banks and caused considerable damage to roads, bridges, farm lands, and crops; the total loss being estimated at $11,000.—*B. Bunnemeyer, Section Director.*

Rains fell nearly continuously over the South Atlantic States on the 14th, 15th, and 16th, resulting in high stages in the streams of Georgia, North Carolina, and South Carolina, but severe floods did not occur.

LAKE LEVELS DURING OCTOBER, 1914.

By UNITED STATES LAKE SURVEY.

[Dated Detroit, Mich., Nov. 3, 1914.]

The stages of the Great Lakes for the month of October, 1914, were as follows:

Data.	Lakes.			
	Superior.	Michigan-Huron.	Erie.	Ontario.
Mean level during October, 1914:	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Above mean sea level at New York	602.75	580.28	572.10	245.59
Above or below—				
Mean stage of September, 1914	−0.05	−0.20	−0.27	−0.50
Mean stage of October, 1913	−0.27	−0.44	−0.33	−0.70
Average stage for October, last 10 years	+0.03	−0.38	−0.08	−0.41
Highest recorded October stage	−0.81	−2.66	−1.60	−2.22
Lowest recorded October stage	+1.17	+0.68	+1.30	+1.92
Probable change during November, 1914	−0.2	−0.3	−0.3	−0.30

SECTION V.—BIBLIOGRAPHY.

RECENT ADDITIONS TO THE WEATHER BUREAU LIBRARY.

By C. FITZHUGH TALMAN, Professor in charge of Library.

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C. FITZHUGH TALMAN, Professor in charge of Library.

The subjoined titles have been selected from the contents of the periodicals and serials recently received in the Library of the Weather Bureau. The titles selected are of papers and other communications bearing on meteorology and cognate branches of science. This is not a complete index of the meterorological contents of all the journals from which it has been compiled. It shows only the articles that appear to the compiler likely to be of particular interest in connection with the work of the Weather Bureau.

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SECTION VI.—WEATHER AND DATA FOR THE MONTH.

THE WEATHER OF THE MONTH.

P. C. DAY, Climatologist and Chief of Division.

Pressure.—The distribution of the mean atmospheric pressure over the United States and Canada, and the prevailing direction of the wind, are graphically shown on Chart VII, while the mean values for the month at the several stations, with the departures from the normal, are shown in Tables I and III.

The mean pressure for the month as a whole was above the normal over most of the country; in fact the only sections showing negative departures comprise the Pacific Coast States and Idaho, the west Gulf States, and local areas in the middle Mississippi and Ohio valleys. However, the positive departures as a rule were small, the greatest values appearing in the northern Rocky Mountain and adjoining Plains States, the Upper Lake region, and the Northeast. The negative departures were likewise small, except that they were quite pronounced in the middle and northern Pacific Coast States.

During the first week of the month no important pressure changes occurred east of the Rocky Mountains, high pressure prevailing in northern districts with relatively low readings to the southward. During this time to the westward of the Rocky Mountains barometric conditions were unsettled, with tendencies to low readings, which advanced eastward and culminated about the close of the first decade in a well-defined storm over the southern Plains States, and moved thence rapidly northeastward and disappeared off the Canadian Maritime Provinces about the 12th. During the following few days pressure readings were high to the westward of the Mississippi, but to the eastward they were relatively low, with unsettled, showery weather.

About the beginning of the third decade low pressure developed in the far Southwest and extended eastward to the Gulf States by the middle of the decade, disappearing off the east Florida coast about the 26th. In the meantime a pronounced high-pressure area moved from the far Northwest, crossing the great central valleys about the 27th and reaching the Southeastern States the following day, but with decreased intensity. During the last few days of the month high pressure obtained quite generally, except for a moderate depression that moved from the region of the Great Lakes to the North Atlantic Ocean.

The distribution of the highs and lows during the month was such as to favor the frequent occurrence of southerly winds in the great central valleys, the Plains States, and from the Lake region eastward, and northeasternly winds over the Southeastern States. From the Rocky Mountains westward the usual variable winds prevailed.

Temperature.—The month opened with warm weather for the season of the year, prevailing over western districts, but in the eastern portion of the country temperatures were somewhat below normal. During the first few days there was a tendency to higher temperatures in the central valleys and the cool weather over eastern districts gave way slowly, so that by the 10th temperatures were generally above normal from the Mississippi Valley eastward.

At the same time cooler weather had advanced from the Pacific coast region and by the morning of the 5th it had extended eastward to the Plains States, and the first widespread severe frosts of the season were reported from the Plateau and Rocky Mountain regions. This cool area rapidly dissipated over the Great Plains, and during the next few days the weather was unseasonably warm in the central valleys and to the eastward, except locally in the Northeastern States, but in the far West cool weather continued.

Early in the second decade of the month cool weather overspread northern districts and it continued cool to the westward of the Rockies, but by the middle of the month temperatures were again near or above the seasonal normal generally and so continued to the end of the decade.

During the last decade warm weather continued over most districts until about the 25th, when high pressure and much colder weather moved southward from the Canadian Northwest Provinces and during the following few days overspread the central valleys and eastern districts. During the progress of this cold area the first general killing frosts of the season occurred over the interior valleys and eastern districts, the line of freezing temperature extending into the central portion of the middle Gulf States and thence northeastward to the New Jersey coast. During the remaining days of the month there was a gradual return to warmer weather and at the close temperatures were again quite high for the season in the central valleys and the Northwest.

For the month as a whole the mean temperature was above the normal in practically all portions of the country, and especially so over the northern districts where the excess ranged very generally from 5° to 10°.

Maximum temperatures were only moderately high, except in a few instances where they were near or equaled the previous record for October.

Minimum temperatures were quite low over eastern and southern districts on the morning of the 28th, especially along the north Atlantic coast where some of the lowest October readings in a period of more than 40 years were recorded.

Precipitation.—During the first week of the month a moderate disturbance persisted in the Gulf of Mexico and the adjoining States, with apparently little change in either location or intensity, during which time showery weather prevailed in the east Gulf and South Atlantic States, with some heavy local falls about the 2d and 3d, but to the northward generally clear weather prevailed during this period.

About the beginning of the month rain set in over the far West and spread slowly eastward. The disturbance responsible for this precipitation was of irregular formation and movement during the first several days of its eastward progress, developing into a well-defined storm only after reaching the southern Plains region near the close of the first decade, but in the meantime showery weather was quite general in western districts. After the 10th the western disturbance moved rapidly from the Mississippi Valley northeastward to the Canadian Maritime Provinces, accompanied by rain over most eastern districts.

From about the 13th to the 18th fair weather was the rule to westward of the Mississippi, but to the eastward unsettled, showery weather prevailed quite generally, breaking for the time being the drought that had persisted in New York and other northeastern States, which had developed into one of the severest on record in portions of that section.

For a few days about the close of the second decade fair weather prevailed generally throughout the country, but early in the third decade general rains set in over the Southwest and during the following few days showers became general from the Rocky Mountains eastward to the Mississippi Valley and extended into the Lake region, with some heavy falls in Texas and New Mexico. From the 26th to the end of the month no precipitation of consequence occurred, except for local showers from the region of the Great Lakes eastward.

For the month as a whole the rainfall was generous to moderately heavy, amounting to from 4 to 6 inches or more in the southeastern States, the southern drainage area of the Ohio, the middle Mississippi and lower Missouri Valleys, and in portions of Texas, while falls of more than 10 inches occurred in the extreme western portions of Washington and Oregon. The precipitation was less than the monthly normals in most of the Atlantic Coast States, especially from Virginia northward, as was also the case in the west Gulf and southern Plains States and portions of the far Southwest. In most other sections of the country the monthly totals were near the normal.

Except in the higher mountain regions of the West and in upper Michigan, no appreciable snow occurred during the month.

GENERAL SUMMARY.

The month, as a whole, was unusually pleasant and favorable for all occupations usual to the season.

In the principal agricultural districts the weather was favorable for the seeding of wheat and the gathering of corn, cotton, and other crops, and there was sufficient soil moisture for the germination of fall-sown grain, except in a few localities.

The absence of general frosts until near the end of the month favored vegetable growth of all kinds. Pastures as a rule continued in excellent condition throughout the month, and stock of all kinds was reported in prime condition to enter the winter. All late crops yielded well and matured properly, and garden vegetables continued in abundance until the killing frosts near the end of the month.

The severe drought that prevailed in portions of the Atlantic Coast States was very generally broken about the middle of the month, although in New Jersey and portions of adjoining States dry weather still continued at the end.

Average accumulated departures for October, 1914.

Districts.	Temperature.			Precipitation.			Cloudiness.		Relative humidity.	
	General mean for the current month.	Departure for the current month.	Accumulated departure since Jan. 1.	General mean for the current month.	Departure for the current month.	Accumulated departure since Jan. 1.	General mean for the current month.	Departure from the normal.	General mean for the current month.	Departure from the normal.
	°F.	°F.	°F.	In.	In.	In.			P. ct.	P. ct.
New England	53.1	+2.7	− 6.3	2.46	−1.20	− 5.10	5.5	+0.1	76	− 3
Middle Atlantic	58.8	+3.4	+ 0.9	1.91	−1.20	− 7.00	5.4	+0.6	77	+ 1
South Atlantic	65.4	+1.7	+ 4.3	3.84	− 0.1	−12.10	5.5	+1.5	81	+ 3
Florida Peninsula	74.7	−1.2	− 4.8	7.80	+2.80	−11.00	5.7	+1.0	79	− 1
East Gulf	65.8	+0.2	− 2.6	2.54	−0.20	− 4.30	5.1	+1.2	80	+ 7
West Gulf	67.8	+1.2	+ 6.9	2.38	−0.40	− 5.40	5.1	+1.4	76	+ 4
Ohio Valley and Tennessee	59.7	+2.9	+ 5.0	3.03	+0.50	− 6.20	5.9	+1.5	78	+ 7
Lower Lakes	55.2	+3.4	− 4.4	2.11	+0.70	− 1.60	5.7	−0.2	79	+ 5
Upper Lakes	53.7	+6.1	+ 9.8	2.14	−0.70	− 0.50	5.5	−0.5	83	+ 5
North Dakota	50.8	+8.2	+22.4	0.83	−0.20	+ 2.70	4.6	−0.6	74	+ 2
Upper Mississippi Valley	57.5	+4.7	+19.6	2.96	−0.50	− 2.80	5.0	+0.4	81	+10
Missouri Valley	57.6	+4.9	+25.6	3.04	+1.20	+ 0.60	4.8	+0.7	74	+ 7
Northern slope	47.3	+2.6	+18.9	1.67	+0.40	− 1.30	5.4	+1.0	70	+10
Middle slope	57.4	+1.8	+22.1	1.75	+0.30	− 3.30	4.3	+0.9	66	+ 7
Southern slope	62.6	+0.2	+ 7.8	4.64	+2.70	+ 5.20	4.8	+0.2	66	+ 3
Southern Plateau	60.1	+0.3	+ 3.7	1.36	+0.70	− 0.50	2.8	+0.6	54	+12
Middle Plateau	51.9	+1.4	+10.8	1.59	+0.70	+ 0.40	3.8	+0.5	56	+ 7
Northern Plateau	52.0	+2.6	+19.0	1.59	+0.50	− 0.60	5.7	+1.1	68	+ 5
North Pacific	54.5	+3.4	+15.6	6.55	+2.60	+ 3.00	7.3	+1.0	84	+ 4
Middle Pacific	59.3	+0.6	+ 5.5	1.52	0.00	− 0.70	4.1	+0.3	70	0
South Pacific	65.8	+3.5	+16.3	0.42	−0.40	+ 3.20	3.2	+0.1	64	− 6

Maximum wind velocities, October, 1914.

Stations.	Date.	Velocity.	Direction.	Stations.	Date.	Velocity.	Direction.
Block Island, R. I.	30	53	nw.	North Head, Wash.	1	60	s.
Buffalo, N. Y.	10	64	sw.		12	58	se.
	11	57	sw.		15	58	se.
	28	63	sw.		16	78	se.
Cleveland, Ohio	26	51	n.		18	76	s.
Corpus Christi, Tex.	12	50	se.		30	50	s.
Modena, Utah	2	50	s.		31	56	se.
Mt. Tamalpais, Cal.	17	72	nw.	Pittsburgh, Pa.	10	54	w.
	28	53	sw.	Sand Key, Fla.	3	52	w.
Mt. Weather, Va.	26	52	nw.		17	50	e.
New York, N. Y.	23	52	nw.	Tatoosh Island, Wash.	16	50	s.
	27	52	nw.		18	56	sw.

CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data, as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course the number of such records is smaller than the total number of stations.

Summary of temperature and precipitation, by sections, October, 1914.

Section.	Temperature—in degrees Fahrenheit. Section average.	Departure from the normal.	Monthly extremes. Station.	Highest.	Date.	Station.	Lowest.	Date.	Precipitation (inches and hundredths). Section average.	Departure from the normal.	Greatest monthly. Station.	Amount.	Least monthly. Station.	Amount.
Alabama	64.2	+0.1	3 stations	90	6†	2 stations	24	28	2.88	+0.43	Alaga	5.79	Flomaton	0.22
Arizona	62.1	+1.3	2 stations	101	1	Snowflake	21	16	2.35	+1.68	Walnut Grove	4.39	Moccasin	0.42
Arkansas	63.0	+1.1	....do	93	6†	Camden	21	28	1.74	−0.83	Conway	5.35	Whitecliffs	0.00
California	60.2	−0.9	Indio	103	13	Bridgeport	13	23	1.60	+0.15	Weitchpec	8.58	8 stations	0.00
Colorado	47.9	+1.6	Lamar	91	3	Dillon	5	14	2.10	+1.00	Durango	5.55	Garnett	T.
Florida	72.9	+0.7	Orange City	94	6	Wausau	30	27	4.01	−0.23	Malabar	11.58	Orange City	1.05
Georgia	64.6	+0.4	Poulan	93	12	Blue Ridge	19	28	4.43	+1.74	Clayton	10.40	St. George	1.87
Hawaii	73.4	......	Waianae, Oahu	93	2	Volcano House	47	28†	4.60	......	Keane Valley, Maui	24.18	6 stations	0.00
Idaho	49.1	+2.5	Grandview	93	16	Pierson	13	6†	1.87	+0.32	Clarks Fork	4.14	Glenns Ferry	0.30
Illinois	58.1	+3.2	2 stations	88	6†	Minonk	18	27	3.13	+0.75	Waterloo	8.08	Martinton	0.94
Indiana	58.1	+3.1	....do	92	6†	Collegeville	18	27	2.37	−0.28	2 stations	4.55	Monticello	0.78
Iowa	55.9	+5.1	Lenox	88	1	Washta	14	27	3.23	+0.77	Corning	6.64	Le Mars	0.74
Kansas	58.3	+1.5	Leoti	95	2	Smith Center	10	27	2.24	+0.33	Lebo	6.43	Hill City	0.21
Kentucky	59.7	+2.0	Farmers	91	6	3 stations	22	28	5.10	+2.82	Franklin	8.49	Weeksbury	2.13
Louisiana	68.3	+0.7	Angola	98	10	Franklinton	21	28	1.68	−1.00	Rayne	5.93	Lake Charles	0.10
Maryland & Delaware	59.3	+3.3	Western Port, Md	93	10	Deerpark, Md	19	27	1.74	−1.22	Frostburg, Md	3.19	Solomons, Md	0.39
Michigan	53.8	+5.2	3 stations	86	5†	2 stations	16	27	2.15	−0.52	Howell	4.51	Escanaba	0.55
Minnesota	52.6	+6.7	Winnebago	93	8	Littlefork	14	26	2.00	−0.19	Park Rapids	4.57	Winton	0.47
Mississippi	65.2	+0.9	Canton	93	10	3 stations	23	28	1.88	−0.22	University	5.30	3 stations	T.
Missouri	59.2	+2.0	2 stations	88	1†	Bethany	19	27	4.54	+2.04	Gano	10.68	Hollister	1.20
Montana	45.7	+1.9	Fallon	92	1	Augusta	9	7†	1.82	+0.87	Belton	5.43	Penwells Ranch	0.38
Nebraska	54.2	+3.3	2 stations	92	2†	2 stations	9	27	1.54	−0.06	Syracuse	5.52	Ashton	0.37
Nevada	51.5	+2.0	Rhyolite	96	14	Quinn River Ranch	14	4†	0.61	−0.07	Jack Creek	2.65	5 stations	0.00
New England	52.6	+3.8	Durham, N. H	87	5	Van Buren, Me	12	28	2.21	−1.37	Bridgeport, Conn	4.90	St. Johnsbury, Vt	0.89
New Jersey	58.1	+4.0	6 stations	88	9†	Woodbine	19	28	1.99	−1.69	Highwood	3.08	Asbury Park	0.90
New Mexico	53.0	−0.1	2 stations	92	7†	Elizabethtown	8	14	2.35	+1.05	Knowles	6.73	Lanark	0.25
New York	52.0	+3.0	Wappingers Falls	88	11	Nehasane	10	28	1.93	−1.48	Scarsdale	4.35	Chazy	0.52
North Carolina	61.5	+2.1	2 stations	89	10†	Mt. Mitchell	14	28	5.07	+1.55	Mt. Mitchell	16.67	Enfield	0.96
North Dakota	50.0	+6.2	Cando	97	2	Turtle Lake	0	26	0.98	−0.06	Larimore	2.05	Lisbon	0.11
Ohio	56.9	+3.8	Portsmouth	91	7	Bellefontaine	17	27	3.42	+0.82	Portsmouth	6.14	Findlay	0.90
Oklahoma	61.7	0.0	Ravia	96	17	Oakwood	19	27	1.45	−1.34	Guymon	5.45	Ardmore	0.05
Oregon	52.4	+1.7	Powell Butte	90	1	Sunrise Valley (2)	15	22†	3.36	+1.04	Glenora	11.24	Glencoe	0.53
Pennsylvania	56.4	+4.5	California	91	10†	Honesdale	11	27	2.35	−0.90	Edinboro	4.37	Hanover	4.89
Porto Rico	78.3	+0.2	2 stations	98	3†	Aibonito	48	20	6.52	−2.30	Maricao	17.50	Ponce	0.95
South Carolina	64.7	+1.6	Blackville	92	11	Liberty	26	28	3.44	+0.32	Liberty	6.51	Allendale	1.70
South Dakota	52.4	+4.6	Clark	96	3	2 stations	11	27	2.03	+0.52	De Smet	5.07	Vermilion	0.50
Tennessee	61.2	+2.3	McMinnville	91	7	Mountain City	16	28	3.50	+0.96	Celina	6.59	Wildersville	1.29
Texas	67.1	0.0	Eagle Pass	100	9	Plemons	20	14	3.46	+0.64	Tivoli	20.45	2 stations	0.00
Utah	51.5	+2.2	Springdale	90	1	Scofield	16	5	1.47	+0.40	Lower Mill Creek	3.87	....do	0.00
Virginia	59.5	+3.1	3 stations	88	9	Burkes Garden	18	28	3.06	−0.11	Roanoke	6.97	Woodstock	1.24
Washington	51.6	+2.0	Kosmos	88	5	2 stations	23	22	3.60	+0.97	Lake Cushman	22.43	Eltopia	0.10
West Virginia	57.3	+2.9	Creston	91	7	Sutton	14	28	2.94	+0.29	Morgantown	6.72	Cortland	1.37
Wisconsin	53.6	+5.6	Hayward	86	2†	Weyerhaeuser	12	27	2.39	−0.05	Menomonee Falls	6.23	Crandon	0.32
Wyoming	45.3	+2.7	Wheatland	92	16	Kirwin	8	7	1.23	+0.24	Gd. Canyon, Y. N. P	3.31	Hyattville	0.00

† Other dates also,

DESCRIPTION OF TABLES AND CHARTS.

Table I gives the data ordinarily needed for climatological studies for about 158 Weather Bureau stations making simultaneous observations at 8 a. m. and 8 p. m., seventy-fifth meridian time, daily, and for about 41 others making only one observation. The altitudes of the instruments above ground are also given.

Table II gives a record of precipitation, the intensity of which at some period of the storm's continuance equaled or exceeded the following rates:

Duration (minutes)	5	10	15	20	25	30	35	40	45	50	60
Rates per hour (inches)	3.00	1.80	1.40	1.20	1.08	1.00	0.94	0.90	0.87	0.84	0.80

It is impracticable to make this table sufficiently wide to accommodate on one line the record of accumulated falls that continue at an excessive rate for several hours. In such cases *the record is broken at the end of each 50 minutes,* the accumulated amounts being recorded on successive lines until the excessive rate ends.

At stations where no storm of sufficient intensity to entitle it to a place in the full table has occurred, the greatest precipitation of any single storm has been given, also the greatest hourly fall during that storm.

Table III gives, for about 30 stations of the Canadian Meterological Service, the means of pressure and temperature, total precipitation, and depth of snowfall, and the respective departures from normal values, except in the case of snowfall.

Chart I.—Hydrographs for several of the principal rivers of the United States.

Chart II.—Tracks of centers of high areas; and

Chart III.—Tracks of centers of low areas. The Roman numerals show the chronological order of the centers. The figures within the circles show the days of the month; the letters *a* and *p* indicate, respectively, the observations at 8 a. m. and 8 p. m., seventy-fifth meridian time. Within each circle is also given (Chart II) the last three figures of the highest barometric reading and (Chart III) the lowest reading reported at or near the center at that time, and in both cases as reduced to sea level and standard gravity.

Chart IV.—Temperature departures. This chart presents the departures of the monthly mean temperatures from the monthly normals. The normals used in computing the departures were computed for a period of 31 years (1873 to 1903) and are published in Weather Bureau Bulletin "R," Washington, 1908. The shaded portions of the chart indicate areas of positive departures and unshaded portions indicate areas of negative departures. Generalized lines connect places having approximately equal departures of like sign. This chart of monthly temperature departures in the United States was first published in the Monthly Weather Review for July, 1909.

Chart V.—Total precipitation. The scale of shades showing the depth is given on the chart. Where the monthly amounts are too small to justify shading, and over sections of the country where stations are too widely separated or the topography is too diversified to warrant reasonable accuracy in shading, the actual depths are given for a limited number of representative stations. Amounts less than 0.005 inch are indicated by the letter T, and no precipitation by 0.

Chart VI.—Percentage of clear sky between sunrise and sunset. The average cloudiness at each Weather Bureau station is determined by numerous personal observations between sunrise and sunset. The difference between the observed cloudiness and 100 is assumed to represent the percentage of clear sky, and the values thus obtained are the basis of this chart. The chart does not relate to the nighttime.

Chart VII.—Isobars and isotherms at sea level and prevailing wind directions. The pressures have been reduced to sea level and standard gravity by the method described by Prof. Frank H. Bigelow on pages 13–16 of the REVIEW for January, 1902. The pressures have also been reduced to the mean of the 24 hours by the application of a suitable correction to the mean of the 8 a. m. and 8 p. m. readings at stations taking two observations daily, and to the 8 a. m. or the 8 p. m. observations, respectively, at stations taking but a single observation. The diurnal corrections so applied will be found in the Annual Report of the Chief of the Weather Bureau, 1900–1901, volume 2, Table 27, pages 140–164.

The isotherms on the sea-level plane have been constructed by means of the data summarized in chapter 8 of volume 2 of the annual report just mentioned. The correction $t_0 - t$, or temperature on the sea-level plane minus the station temperature as given by Table 48 of that report, is added to the observed surface temperature to obtain the adopted sea-level temperature.

The prevailing wind directions are determined from hourly observations at the great majority of the stations; a few stations having no self-recording wind direction apparatus determine the prevailing direction from the daily or twice-daily observations only.

Chart VIII.—Total snowfall. This is based on the reports from regular and cooperative observers and shows the depth in inches and tenths of the snowfall during the month. In general, the depth is shown by lines inclosing areas of equal snowfall, but in special cases figures are also given.

Chart VIII is published only when the general snow cover is sufficiently extensive to justify its preparation.

TABLE I.—*Climatological data for United States Weather Bureau stations, October, 1914.*

Districts and stations.	Elevation of instruments: Barometer above sea level, feet.	Elevation of instruments: Thermometer above ground.	Elevation of instruments: Anemometer above ground.	Pressure in inches: Station, reduced to mean of 24 hours.	Pressure in inches: Sea level, reduced to mean of 24 hours.	Pressure in inches: Departure from normal.	Temperature of the air, in degrees Fahrenheit: Mean max.+mean min.÷2.	Temperature: Departure from normal.	Temperature: Maximum.	Temperature: Date.	Temperature: Mean maximum.	Temperature: Minimum.	Temperature: Date.	Temperature: Mean minimum.	Temperature: Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches: Total.	Precipitation: Departure from normal.	Precipitation: Days with 0.01 or more.	Wind: Total movement, miles.	Wind: Prevailing direction.	Wind: Maximum velocity: Miles per hour.	Wind: Maximum velocity: Direction.	Wind: Maximum velocity: Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
New England.							**53.1**	**+ 2.7**										**76**	**2.46**	**− 1.2**										**5.5**		
Eastport	76	67	85	29.97	30.05	+0.05	49.2	+ 2.6	76	3	56	24	28	42	28	45	41	75	2.56	− 1.3	9	7,891	sw.	41	ne.	19	11	10	10	5.7	T.	...
Greenville	1,070	6	...	28.84	30.04	...	46.6	...	76	4	57	16	28	36	42	...	...	...	3.07	...	10	...	...	...	...	...	...	...	...	...	1.5	...
Portland, Me.	103	82	117	29.96	30.09	+ .05	51.2	+ 2.1	81	5	60	22	28	42	38	46	41	71	2.05	− 1.6	5	6,660	sw.	30	sw.	24	14	8	9	4.9	T.	...
Concord	288	70	79	29.79	30.10	+ .05	51.2	+ 2.5	81	4	63	21	28	39	40	...	...	...	1.12	− 2.1	6	3,288	nw.	28	nw.	27	8	9	14	6.0	...	...
Burlington	404	11	48	29.64	30.08	+ .04	50.2	+ 3.3	76	5	59	22	27	41	35	...	...	...	1.10	− 2.1	8	8,163	s.	36	s.	10	8	8	15	6.3	0.6	...
Northfield	876	12	60	29.14	30.10	+ .06	47.9	+ 4.3	77	4	60	17	28	36	44	43	41	84	1.00	− 1.5	7	4,713	s.	25	nw.	31	7	8	16	6.5	0.1	...
Boston	125	115	188	29.95	30.09	+ .04	57.0	+ 4.7	83	3	66	29	28	49	31	51	47	75	1.54	− 2.3	5	6,766	sw.	28	nw.	27	15	7	9	4.7	T.	...
Nantucket	12	14	90	30.08	30.09	+ .04	56.2	+ 1.7	74	4	62	33	28	50	24	52	50	84	2.15	− 1.2	7	10,787	sw.	43	sw.	29	7	16	8	5.5	...	...
Block Island	26	11	46	30.06	30.09	+ .04	56.4	+ 1.1	70	5	62	34	27	51	18	53	50	81	3.33	− 0.8	5	11,989	sw.	53	nw.	30	7	10	14	6.2	...	...
Narragansett Pier	...	9	...	...	...	...	55.2	+ 3.1	75	3	63	24	28	48	27	...	...	...	4.26	...	4	...	sw.	...	...	...	16	11	4	...	...	...
Providence	160	215	251	29.92	30.09	+ .02	55.6	+ 3.4	79	3	64	27	28	47	30	50	46	74	2.97	− 0.9	5	7,737	sw.	44	nw.	27	12	15	4	4.3	...	...
Hartford	159	122	140	29.91	30.09	+ .03	56.4	+ 5.2	82	3	66	26	28	47	41	49	44	71	3.05	− 0.8	5	4,725	s.	27	nw.	30	9	11	11	5.5	T.	...
New Haven	106	117	155	29.98	30.10	+ .04	57.0	+ 4.2	79	11	66	28	28	49	30	51	46	72	3.81	− 0.1	5	5,892	s.	30	sw.	29	11	10	10	5.2	T.	...
Middle Atlantic States.							**58.8**	**+ 3.4**										**77**	**1.91**	**− 1.2**										**5.4**		
Albany	97	102	115	29.98	30.09	+ .03	54.6	+ 4.2	82	11	64	30	28	45	36	48	44	74	0.84	− 2.2	5	5,039	s.	28	s.	10	13	9	9	4.7	T.	...
Binghamton	871	10	69	29.16	30.10	+ .04	54.0	+ 4.8	82	10	63	28	27	44	38	...	...	...	1.47	− 1.6	11	3,136	s.	18	nw.	27	7	12	12	5.9	T.	...
New York	314	414	454	29.76	30.09	+ .03	59.0	+ 3.4	80	11	66	31	28	52	23	52	47	70	1.92	− 1.8	4	10,814	sw.	52	nw.	27	8	11	12	5.6	...	...
Harrisburg	374	94	104	29.71	30.12	+ .04	58.2	+ 4.2	81	10	66	32	27	50	27	52	48	74	1.36	− 1.6	8	3,896	e.	25	n.	26	10	8	13	5.6	...	...
Philadelphia	117	123	190	29.99	30.12	+ .05	61.2	+ 4.9	85	10	68	33	28	54	22	54	51	75	1.49	− 1.6	4	6,243	sw.	33	nw.	27	11	8	12	5.3	...	...
Reading	325	81	98	29.76	30.11	...	58.6	...	82	10	67	31	27	50	31	51	47	72	1.40	− 1.9	6	4,082	se.	29	nw.	27	8	7	16	6.3	T.	...
Scranton	805	111	119	29.24	30.11	+ .04	55.8	+ 4.4	82	10	64	29	27	48	36	51	49	85	1.05	− 1.9	5	4,428	n.	26	nw.	26	7	15	9	5.7	T.	...
Atlantic City	52	37	48	30.05	30.11	+ .04	59.8	+ 2.4	75	11	65	32	28	54	21	55	51	77	2.25	− 1.0	6	5,534	sw.	23	nw.	27	12	5	14	5.6	...	...
Cape May	18	13	49	30.11	30.13	+ .06	61.5	+ 1.9	82	11	68	37	27	56	21	...	...	...	2.15	− 1.2	6	6,293	e.	34	nw.	27	10	14	7	5.2	...	...
Trenton	190	159	183	29.89	30.09	...	59.0	...	84	10	68	31	28	50	31	52	48	75	1.74	− 1.7	3	7,120	s.	36	nw.	30	10	9	12	5.7	T.	...
Baltimore	123	100	113	29.98	30.11	+ .03	61.4	+ 3.9	85	10	69	33	28	54	23	55	51	73	1.24	− 1.8	3	4,728	sw.	30	n.	26	11	10	10	5.2	...	...
Washington	112	62	85	29.98	30.10	+ .02	60.2	+ 3.6	86	10	69	33	28	51	33	54	51	78	1.65	− 1.4	7	3,802	s.	27	nw.	30	13	6	12	5.4	...	...
Lynchburg	681	153	188	29.35	30.10	+ .01	60.9	+ 4.0	85	9	71	29	28	51	33	53	50	78	4.42	+ 1.0	10	4,082	ne.	30	n.	27	10	12	9	5.4	...	...
Mount Weather	1,725	10	75	28.26	30.08	− .01	55.9	+ 4.4	77	10	62	26	27	49	23	50	47	77	2.40	0.0	11	9,940	e.	52	nw.	26	7	11	13	6.6	...	...
Norfolk	91	170	205	30.01	30.11	+ .04	63.9	+ 2.6	84	9	70	37	28	58	25	58	55	80	2.39	− 1.5	9	8,880	ne.	42	n.	27	11	11	9	5.5	...	...
Richmond	144	11	52	29.96	30.11	+ .03	61.8	+ 2.0	85	9	71	29	28	52	32	55	51	76	1.67	− 1.6	8	5,000	ne.	30	nw.	27	14	9	8	4.5	...	...
Wytheville	2,293	40	47	27.73	30.11	+ .02	55.4	+ 1.8	81	9	65	24	28	46	35	50	48	87	3.04	− 0.1	16	2,605	e.	19	nw.	30	16	8	7	4.4	...	...
South Atlantic States.							**65.4**	**+ 1.7**										**81**	**3.84**	**− 0.1**										**5.5**		
Asheville	2,255	70	84	27.76	30.11	+ .02	57.8	+ 2.5	81	7	67	23	28	48	39	52	49	82	5.83	+ 2.9	9	5,060	se.	29	e.	3	8	10	13	6.0	...	...
Charlotte	773	68	76	29.26	30.10	+ .02	62.2	+ 1.1	81	7	70	30	28	54	25	56	53	80	3.11	0.0	6	4,547	ne.	22	sw.	17	10	6	15	6.0	...	...
Hatteras	11	12	50	30.07	30.08	+ .02	67.0	+ 1.0	79	11	72	44	28	62	22	62	60	82	5.78	− 0.2	8	8,939	ne.	47	n.	27	11	8	12	5.3	...	...
Manteo	12	4	46	...	...	...	65.0	...	83	11	72	33	29	58	...	...	...	...	2.20	− 3.8	7	...	ne.	...	...	...	17	6	8	...	...	...
Raleigh	376	103	110	29.69	30.09	+ .02	63.2	+ 2.7	84	9	71	32	28	55	28	57	53	77	1.17	− 2.3	9	4,752	ne.	28	nw.	26	12	6	13	5.6	...	...
Wilmington	78	81	91	30.00	30.08	+ .02	65.8	+ 2.5	86	11	74	34	28	58	27	60	58	82	4.84	+ 1.1	11	4,745	ne.	30	n.	27	11	8	12	5.6	...	...
Charleston	48	11	92	30.01	30.06	.00	68.4	+ 1.3	84	11	74	40	28	62	22	63	61	82	4.14	+ 0.2	11	6,735	ne.	36	e.	3	13	5	13	5.3	...	...
Columbia, S. C.	351	41	57	29.70	30.08	+ .01	64.4	+ 0.4	86	11	73	34	28	56	33	58	54	76	2.70	− 0.2	8	4,648	ne.	26	n.	27	14	6	11	4.9	...	...
Augusta	180	89	97	29.88	30.07	.00	65.0	+ 1.4	86	11	74	34	29	56	34	59	57	84	2.89	+ 0.6	9	3,849	ne.	27	nw.	27	12	7	12	5.4	...	...
Savannah	65	150	194	29.98	30.05	.00	68.8	+ 2.5	88	11	76	40	28	62	22	63	61	84	7.28	+ 3.7	9	7,246	ne.	31	ne.	2	11	8	12	5.6	...	...
Jacksonville	43	96	129	29.98	30.03	+ .01	71.5	+ 1.9	86	11	79	46	28	64	21	66	64	85	2.34	− 2.7	8	5,771	ne.	37	sw.	15	12	6	13	5.7	...	...
Florida Peninsula.							**74.7**	**− 1.2**										**79**	**7.80**	**+ 2.8**										**5.7**		
Key West	22	10	64	29.92	29.94	.00	78.3	− 0.4	88	16	83	70	3	74	17	73	70	79	9.20	+ 3.8	12	6,946	ne.	49	w.	3	11	9	11	5.3	...	...
Miami	25	71	79	29.94	29.97	...	76.0	− 1.8	85	16	81	64	28	71	15	71	69	79	6.92	− 3.6	20	5,962	e.	38	sw.	1	4	13	14	6.9	...	...
Sand Key	23	39	72	29.90	29.93	− .01	78.3	...	85	16	81	70	17	76	12	73	71	77	10.64	...	15	10,297	e.	52	w.	3	12	10	9	4.9	...	...
Tampa	35	79	96	29.95	29.99	+ .01	74.2	+ 1.6	88	10	82	52	28	66	24	67	65	81	4.45	+ 1.5	11	4,794	ne.	27	ne.	22	8	13	10	5.6	...	...
Titusville	44	6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
East Gulf States.							**65.8**	**+ 0.2**										**80**	**2.54**	**− 0.2**										**5.1**		
Atlanta	1,174	190	216	28.85	30.09	+ .02	62.4	0.0	80	9	70	35	28	55	24	56	53	77	6.14	+ 3.8	9	6,703	e.	38	w.	13	12	5	14	5.6	...	...
Macon	370	78	87	29.66	30.06	.00	63.6	− 0.1	84	11	73	33	29	54	35	58	56	83	3.29	+ 1.2	10	3,859	ne.	26	nw.	26	23	6	12	5.2	...	...
Thomasville	273	8	57	29.74	30.03	− .01	68.2	0.0	88	12	79	34	28	58	34	61	59	87	2.17	− 1.3	7	3,025	ne.	23	s.	13	14	8	9	4.6	...	...
Pensacola	56	140	182	29.96	30.02	− .01	68.8	− 0.6	83	10	75	38	28	62	24	62	59	76	1.06	− 3.0	3	8,384	ne.	36	ne.	27	9	13	9	5.5	...	...
Anniston	741	9	57	29.29	30.09	+ .02	62.6	+ 0.2	83	9	72	27	28	53	40	...	...	...	3.26	+ 0.9	8	3,283	se.	23	e.	2	10	9	12	5.3	...	...
Birmingham	700	11	48	29.32	30.08	+ .01	63.8	− 0.6	84	5	72	30	28	55	32	57	54	79	2.52	+ 0.2	6	4,174	e.	25	nw.	10	10	11	10	5.1	...	...
Mobile	57	125	161	29.97	30.03	− .01	68.8	+ 1.7	85	6	77	37	28	61	27	62	59	79	0.75	− 2.4	7	6,304	ne.	35	n.	27	11	12	8	4.6	...	...
Montgomery	223	100	112	29.81	30.06	.00	65.2	− 0.5	85	10	74	35	28	56	31	59	55	77	3.46	+ 1.0	7	4,293	ne.	25	ne.	10	10	11	10	5.1	...	...
Meridian	375	85	93	29.66	30.06	.00	64.0	+ 1.0	87	10	72	30	28	56	32	58	56	84	1.71	− 1.0	6	3,398	ne.	18	n.	27	11	8	12	5.7	...	...
Vicksburg	247	65	74	29.78	30.06	.00	66.3	+ 1.0	86	10	75	36	28	58	26	60	57	81	0.90	− 1.9	6	4,550	e.	17	s.	12	14	10	7	4.6	...	...
New Orleans	51	90	121	29.96	30.01	− .02	70.3	+ 0.8	90	10	77	45	28	64	22	64	62	82	2.63	− 0.3	5	5,768	ne.	33	ne.	11	11	12	8	5.0	...	...
West Gulf States.							**67.8**	**+ 1.2**										**76**	**2.38**	**− 0.4**										**5.1**		
Shreveport	249	77	93	29.78	30.05	.00	66.8	+ 1.2	91	10	76	35	28	57	34	59	55	75	0.32	− 2.9	3	4,790	se.	23	nw.	12	10	9	12	5.6	...	...
Bentonville	1,303	11	44	28.68	30.05	.00	59.7	+ 1.7	84	6	70	28	27	50	36	...	...	...	3.01	+ 0.2	7	3,356	se.	19	n.	26	13	4	14	5.6	...	...
Fort Smith	457	79	94	29.56	30.04	− .01	63.1	+ 1.4	87	8	72	34	28	54	35	55	51	75	1.38	− 1.4	6	5,451	e.	31	nw.	9	11	4	16	5.6	...	...
Little Rock	357	139	147	29.68	30.06	.00	63.2	+ 0.3	84	8	72	34	28	55	32	58	55	80	1.47	− 1.1	9	5,629	e.	39	n.	9	13	7	11	5.4	...	...
Brownsville	57	3	40	...	...	...	75.1	...	95	10	85	54	16	65	32	...	...	...	2.58	...	7	...	e.	...	...	...	...	...	...	...	...	...
Corpus Christi	20	69	77	29.97	29.99	− .01	72.8	+ 0.2	85	7	79	52	15	66	27	67	65	82	5.19	+ 3.1	9	8,590	s.e	50	se.	12	10	11	10	4.9	...	...
Dallas	512	109	117	29.49	30.03	...	66.4	...	89	17	77	37	27	56	40	...	...	...	0.35	...	4	6,423	se.	26	s.	9	10	12	9	5.1	...	...
Fort Worth	670	106	114	29.30	30.01	− .02	66.2	− 0.1	90	17	76	37	27	56	38	58	53	69	0.28	− 2.2	6	7,005	se.	34	sw.	12	11	9	11	5.3	...	...
Galveston	54	106	114	29.96	30.02	− .01	71.7	− 0.7	85	9	76	54	15	67	16	67	64	81	2.95	− 1.2	9	8,725	n.	36	s.	19	17	8	6	3.8	...	...
Houston	138	111	121	29.86	30.00	...	70.7	+ 0.8	93	10	79	44	28	62	28	...	...	...	2.53	...	9	5,729	se.	29	e.	12	11	7	13	5.5	...	...
Palestine	510	64	72	29.49	30.02	− .01	67.3	+ 1.1	89	10	76	39	28	58	32	60	56	76	1.37	− 2.2	9	4,850	se.	22	s.	9	10	9	12	5.1	...	...
San Antonio	701	109	132	29.28	30.00	− .01	70.2	+ 1.0	93	10	80	45	15	60	31	62	58	74	5.78	+ 4.3	5	4,895	ne.	25	ne.	23	11	10	10	5.1	...	...
Taylor	582	55	63	29.43	30.04	+ .02	68.0	− 0.3	91	10	79	38	28	57	38	...	...	...	3.69	+ 1.1	5	5,601	nw.	25	e.	11	11	14	6	4.6	...	...

TABLE I.—*Climatological data for United States Weather Bureau stations, October, 1914*—Continued.

Districts and stations.	Elevation of instruments.			Pressure in inches.			Temperature of the air, in degrees Fahrenheit.									Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches.			Wind.					Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Barometer above sea level, feet.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.				Total.	Departure from normal.	Days with 0.01 or more.	Total movement, miles.	Prevailing direction.	Maximum velocity. Miles per hour.	Maximum velocity. Direction.	Maximum velocity. Date.						
Ohio Valley and Tennessee.							**59.7**	**+2.9**										**78**	**3.03**	**+0.5**										**5.9**		
Chattanooga	762	189	213	29.28	30.10	+.01	62.4	+1.6	83	8	71	31	28	54	31	55	52	75	2.93	+0.1	6	4,485	w.	33	nw.	26	9	10	12	5.6	.....	....
Knoxville	996	93	100	29.03	30.08	−.01	61.2	+3.1	84	9	70	28	28	52	32	55	53	81	3.57	+1.0	7	3,137	ne.	23	n.	26	10	7	14	6.2	.....	....
Memphis	399	76	97	29.67	30.10	+.03	63.3	+0.8	82	9	71	35	27	56	23	57	54	77	1.81	−0.9	10	5,275	s.	28	sw.	10	11	5	15	6.0	.....	....
Nashville	546	168	191	29.50	30.09	+.01	61.9	+1.6	83	1	71	28	28	53	31	56	53	78	2.80	+0.3	8	5,084	w.	40	nw.	26	10	8	13	5.8	.....	....
Lexington	989	75	102	29.00	30.07	−.01	58.9	+2.4	84	7	67	26	27	51	25	....	....	....	5.32	+3.1	11	5,738	ne.	31	nw.	26	9	9	13	6.0	.....	....
Louisville	525	219	255	29.50	30.09	+.01	60.7	+2.3	84	6	69	30	27	52	26	55	53	81	2.42	−0.2	10	6,592	n.	44	w.	10	8	8	15	5.8	.....	....
Evansville	431	72	82	29.60	30.07	.00	60.8	+2.8	84	6	69	30	27	53	24	54	51	78	2.75	−0.4	8	4,284	s.	34	s.	9	11	6	14	5.8	.....	....
Indianapolis	822	154	164	29.19	30.08	+.01	58.4	+3.4	82	6	67	29	27	50	30	52	49	78	1.67	−1.1	9	5,346	sw.	34	sw.	10	9	6	16	6.1	T.	....
Terre Haute	575	96	129	29.44	30.06	......	59.0	......	83	6	68	28	27	50	30	53	50	80	2.46	......	6	5,533	s.	36	nw.	26	9	9	13	5.9	.....	....
Cincinnati	628	152	160	29.40	30.08	.00	60.5	+3.5	86	7	68	29	27	52	28	54	51	77	3.59	+1.3	9	3,730	se.	25	w.	10	8	6	17	6.5	.....	....
Columbus	824	173	222	29.21	30.09	+.01	57.7	+3.6	82	5	66	25	27	49	30	52	48	77	4.44	+2.1	13	6,745	se.	42	n.	26	9	9	13	5.5	.....	....
Dayton	899	181	216	29.10	30.06	......	58.4	+4.3	81	6	67	26	27	50	33	52	49	78	3.48	+1.1	14	6,067	s.	42	s.	10	12	9	10	5.2	.....	....
Pittsburgh	842	353	410	29.19	30.10	+.02	58.4	+3.5	84	10	67	30	27	50	30	51	47	73	3.07	+0.7	15	7,165	w.	54	w.	10	11	9	11	5.6	T.	....
Elkins	1,940	41	50	28.06	30.13	+.03	55.2	+3.8	86	10	67	24	28	44	40	48	45	85	2.25	−0.2	15	2,305	w.	22	w.	17	8	13	10	5.9	0.5	....
Parkersburg	638	77	84	29.45	30.11	+.03	59.2	+4.6	84	6	69	29	27	49	33	52	48	77	2.91	+0.5	11	3,126	se.	30	sw.	10	9	8	14	6.1	.....	....
Lower Lake Region.							**55.2**	**+3.4**										**79**	**2.11**	**−0.7**										**5.7**		
Buffalo	767	247	280	29.24	30.08	+0.3	55.2	+3.7	78	10	62	28	27	49	28	51	49	84	1.80	−1.7	10	11,679	sw.	64	sw.	10	6	8	17	7.0	T.	....
Canton	448	10	61	29.59	30.07	......	50.4	+3.2	79	9	60	24	14	40	37	....	....	....	1.82	−1.5	12	7,281	sw.	40	w.	11	12	7	12	5.4	0.5	....
Oswego	335	76	91	29.70	30.07	+.02	53.2	+2.0	79	9	61	30	27	46	25	48	45	76	1.34	−2.0	10	6,908	s.	38	ne.	24	11	7	13	5.6	T.	....
Rochester	523	97	113	29.52	30.10	+.05	54.6	+3.8	81	9	62	30	27	47	30	49	45	76	2.04	−0.8	10	5,378	sw.	31	sw.	11	10	7	14	5.9	0.8	....
Syracuse	597	97	113	29.45	30.10	+.04	53.8	+2.8	79	10	62	25	27	46	27	48	45	76	1.21	−2.0	12	6,925	s.	30	sw.	28	10	7	14	5.7	2.4	....
Erie	714	92	102	29.30	30.08	+.03	56.2	+3.1	81	10	63	32	27	50	23	51	46	74	3.50	−0.3	12	7,130	s.	31	se.	14	8	9	14	5.9	0.1	....
Cleveland	762	190	201	29.26	30.08	+.02	56.8	+3.7	78	8	63	33	28	51	20	52	49	79	2.39	−0.3	10	9,113	se.	51	n.	26	10	7	14	5.7	T.	....
Sandusky	629	62	103	29.39	30.08	+.02	57.2	+3.3	80	8	64	33	27	50	26	52	49	80	1.58	−0.8	12	8,165	sw.	40	n.	26	11	6	14	5.5	.....	....
Toledo	628	208	246	29.40	30.09	+.04	56.5	+3.9	80	21	64	26	27	49	27	52	49	82	2.68	+0.4	8	9,601	sw.	44	sw.	10	10	9	12	5.2	.....	....
Fort Wayne	856	113	124	29.15	30.08	......	56.3	+2.6	81	7	65	25	27	47	29	51	48	79	2.76	......	9	5,421	sw.	31	sw.	28	9	8	14	5.5	T.	....
Detroit	730	218	245	29.28	30.08	+.03	56.6	+4.9	78	5	64	26	27	49	24	51	48	81	2.12	−0.3	10	8,201	sw.	34	sw.	28	11	7	13	5.7	T.	....
Upper Lake Region.							**53.7**	**+6.1**										**83**	**2.14**	**−0.7**										**5.5**		
Alpena	609	13	92	29.40	30.07	+.04	51.4	+5.5	78	20	58	26	27	45	35	48	45	84	2.92	−0.5	11	7,204	se.	33	w.	11	9	6	16	6.1	T.	....
Escanaba	612	54	60	29.38	30.05	+.04	51.4	+6.3	70	21	59	23	27	44	24	48	45	84	0.55	−2.5	8	6,608	ne.	35	n.	23	12	8	11	5.2	0.2	....
Grand Haven	632	54	92	29.37	30.05	+.02	54.8	+4.6	76	7	62	29	26	48	29	51	48	83	2.55	+0.1	10	7,422	w.	42	w.	10	13	8	10	4.5	T.	....
Grand Rapids	707	70	87	29.29	30.06	+.02	56.5	+6.4	82	7	65	28	27	48	29	51	48	80	2.72	+0.2	9	3,779	e.	24	w.	10	8	9	14	6.1	T.	....
Houghton	684	62	72	29.30	30.03	+.03	51.6	+6.5	80	4	60	25	26	43	30	....	....	....	1.18	−2.0	8	5,656	w.	37	n.	23	8	8	15	6.2	1.0	....
Lansing	878	11	62	29.12	30.07	......	54.6	+5.9	81	7	65	23	27	44	38	48	46	87	2.81	+0.6	11	3,566	sw.	19	n.	26	12	7	12	5.2	T.	....
Ludington	637	60	66	29.35	30.05	......	54.5	......	75	6	61	30	26	48	27	51	49	86	3.00	......	11	7,202	s.	32	w.	27	14	5	12	4.9	T.	....
Marquette	734	77	111	29.26	30.07	+.06	52.9	+5.4	80	20	61	25	27	45	35	47	43	77	1.03	−2.2	9	7,185	sw.	35	nw.	23	10	4	17	6.4	2.0	....
Port Huron	638	70	120	29.37	30.06	+.02	54.0	+4.5	78	21	62	25	27	46	29	50	47	84	1.66	−1.1	11	7,341	sw.	34	ne.	24	11	9	11	5.3	.....	....
Saginaw	641	48	82	29.37	30.07	......	54.6	......	79	7	64	24	27	45	33	50	48	87	1.75	−1.0	9	5,785	s.	27	nw.	26	10	9	12	5.5	.....	....
Sault Sainte Marie	614	11	61	29.37	30.07	+.06	50.2	+6.8	75	5	58	22	27	42	30	46	43	85	1.47	−1.8	12	5,261	e.	37	w.	11	8	7	16	6.6	0.1	....
Chicago	823	140	310	29.17	30.06	+.02	59.4	+6.2	81	7	65	28	27	54	24	54	50	75	2.89	+0.3	10	7,810	sw.	34	n.	26	14	5	12	4.8	T.	....
Green Bay	617	109	144	29.38	30.04	+.02	54.8	+7.7	79	6	63	23	27	46	31	49	46	81	1.73	−0.6	11	7,902	s.	48	n.	23	12	6	13	6.1	T.	....
Milwaukee	681	119	133	29.31	30.05	+.02	56.2	+6.0	80	7	63	27	27	50	31	52	48	80	4.75	+2.4	10	6,865	sw.	40	e.	13	14	5	12	5.2	T.	....
Duluth	1,133	11	47	28.82	30.05	+.05	49.2	+4.0	78	4	56	20	26	42	29	45	43	88	1.14	−1.6	7	9,606	ne.	39	w.	27	13	8	10	5.1	T.	....
North Dakota.							**50.8**	**+8.2**										**74**	**0.83**	**−0.2**										**4.6**		
Moorhead	940	8	57	28.99	30.02	+.02	52.8	+10.0	36	1	65	21	27	41	39	46	43	80	0.99	−1.1	7	6,203	se.	28	n.	23	18	7	6	3.3	.....	....
Bismarck	1,674	8	57	28.24	30.04	+.05	51.0	+6.9	89	1	65	21	26	37	48	42	37	73	0.79	−0.2	8	6,582	nw.	34	se.	5	15	6	10	4.3	T.	....
Devils Lake	1,482	11	44	28.39	29.97	+.02	50.8	+10.3	89	1	62	19	26	39	36	42	38	74	1.15	−0.1	7	7,421	sw.	31	n.	23	14	8	9	4.9	.....	
Williston	1,872	40	47	27.98	29.98	.00	48.8	+5.9	83	17	62	17	26	36	45	41	35	68	0.38	−0.4	6	4,262	sw.	30	nw.	31	8	12	11	5.8	T.	....
Upper Mississippi Valley.							**57.5**	**+4.7**										**81**	**2.96**	**+0.5**										**5.0**		
Minneapolis	918	10	208	29.02	30.00	......	55.4	......	81	1	65	26	27	46	29	....	....	....	1.58	−1.0	5	8,187	s.	36	s.	4	16	10	5	4.0	.....	....
St. Paul	837	201	236	29.12	30.03	+.02	55.4	+7.3	80	1	65	24	27	46	32	....	....	....	1.88	−0.5	7	8,092	s.	44	s.	4	15	8	8	4.5	.....	....
La Crosse	714	11	48	29.27	30.05	+.03	56.0	+6.1	79	20	66	24	27	46	31	....	....	....	2.79	+0.3	9	3,511	s.	21	n.	26	10	11	10	5.5	T.	....
Madison	974	70	78	29.01	30.06	+.03	55.4	+6.6	78	6	64	25	27	47	27	50	47	80	3.09	+0.7	8	6,792	s.	44	ne.	24	12	8	11	5.6	T.	....
Charles City	1,015	10	49	28.96	30.05	+.03	54.9	+6.7	78	1	65	22	27	45	33	50	48	87	3.96	+1.9	10	4,665	se.	28	n.	26	11	11	9	4.9	.....	....
Davenport	606	71	79	29.39	30.05	+.01	58.0	+5.4	81	6	67	25	27	49	29	52	49	80	2.15	−0.2	9	4,160	e.	27	n.	26	15	5	11	4.9	T.	....
Des Moines	861	84	97	29.11	30.02	+.01	57.4	+4.9	79	1	66	24	27	48	31	52	49	80	3.57	+0.9	10	5,270	s.	29	sw.	31	14	4	13	5.1	.....	....
Dubuque	698	81	96	29.31	30.06	+.02	56.7	+4.7	78	6	65	26	27	48	28	50	47	78	2.88	+0.2	10	3,760	s.	26	n.	26	12	7	12	5.5	T.	....
Keokuk	614	64	78	29.38	30.06	+.01	58.8	+4.3	83	6	68	24	27	50	30	53	50	80	1.65	−0.8	7	4,213	se.	22	nw.	26	16	6	9	4.5	.....	....
Cairo	356	87	93	29.67	30.06	−.01	61.5	+2.4	84	6	70	32	27	54	22	56	53	82	2.45	−0.2	8	4,938	s.	37	sw.	9	12	6	13	5.5	.....	....
Peoria	609	11	45	29.40	30.07	+.02	57.2	+5.2	84	7	68	22	27	47	33	51	48	86	2.15	−0.4	10	3,662	s.	26	n.	26	11	10	10	5.1	.....	....
Springfield, Ill.	644	10	91	29.37	30.06	+.01	58.1	+3.5	81	7	67	27	27	49	28	52	48	77	2.08	−0.5	8	4,770	s.	28	nw.	26	12	7	12	5.4	.....	....
Hannibal	534	74	109	29.48	30.05	.00	58.8	+2.9	83	6	68	26	27	50	33	....	....	....	3.69	+2.0	8	5,257	sw.	26	n.	26	15	8	8	4.5	.....	....
St. Louis	567	265	303	29.44	30.05	−.01	60.8	+2.4	82	6	69	31	27	53	26	55	52	79	7.45	+5.0	7	7,599	s.	36	n.	26	12	9	10	5.1	.....	....
Missouri Valley.							**57.6**	**+4.9**										**74**	**3.04**	**+1.2**										**4.8**		
Columbia, Mo.	781	11	84	29.21	30.04	−.01	58.8	+4.0	84	6	68	25	27	50	36	....	....	....	5.14	+2.7	8	4,712	se.	25	nw.	26	11	4	16	6.1	.....	....
Kansas City	963	161	181	29.01	30.05	+.01	60.0	+4.2	80	6	68	30	27	52	28	53	48	71	5.65	+3.4	12	8,566	se.	42	n.	9	12	7	12	5.2	.....	....
St. Joseph	967	11	49	29.01	30.05	......	58.8	......	82	6	67	25	27	50	33	52	49	78	3.16	......	10	5,763	se.	32	nw.	12	12	9	10	5.1	.....	....
Springfield, Mo.	1,324	98	104	28.66	30.07	+.02	58.8	+1.5	82	8	67	28	27	51	26	52	48	76	2.84	0.0	6	6,864	se.	44	nw.	9	14	3	14	4.8	.....	....
Iola	984	11	50	29.01	30.06	+.02	58.9	+2.0	84	7	60	26	27	49	38	....	....	....	4.65	+2.4	12	4,607	s.	24	nw.	9	10	10	11	5.1	.....	....
Topeka	983	85	101	......	......	......	58.6	+2.3	81	6	68	26	27	49	38	....	....	....	3.05	+1.1	10	6,856	s.	30	nw.	12	12	8	11	5.1	.....	....
Lincoln	1,189	11	84	28.76	30.03	.00	57.2	+3.9	82	2	47	24	27	68	39	51	47	78	2.75	+0.9	11	7,710	s.	33	nw.	28	15	4	12	4.6	.....	....
Omaha	1,105	115	121	28.85	30.04	+.01	57.8	+3.6	81	2	67	27	27	49	34	51	47	76	3.70	+1.4	10	6,179	s.	31	n.	26	16	3	12	4.7	.....	....
Valentine	2,598	47	54	27.31	30.04	+.03	52.0	+3.5	85	18	65	26	29	47	45	43	37	68	1.79	+0.5	7	6,993	w.	33	se.	22	15	7	9	4.3	.....	....
Sioux City	1,135	94	164	28.81	30.03	+.01	55.6	+4.5	80	2	66	23	27	45	39	49	45	76	1.81	0.0	7	9,010	se.	42	s.	3	16	5	10	4.3	.....	....
Huron	1,306	59	74	28.64	30.05	+.04	53.0	+8.3	85	2	66	20	27	40	40	45	41	76	2.35	+1.0	7	8,015	se.	36	se.	3	15	9	7	4.0	.....	....
Pierre	1,572	70	75	28.38	30.05	+.04	54.0	+4.4	89	2	66	27	14	42	45	44	38	63	1.95	+1.1	7	6,381	se.	34	ne.	23	19	5	7	3.6	.....	....
Yankton	1,233	49	57	28.70	30.02	+.01	55.5	+5.0	85	18	67	22	27	44	46	....	....	....	0.70	−0.9	7	5,396	nw.	28	n.	12	16	3	12	4.8	.....	....

TABLE I.—*Climatological data for United States Weather Bureau stations, October, 1914*—Continued.

Districts and stations.	Elevation of instruments: Barometer above sea level, feet.	Elevation of instruments: Thermometer above ground.	Elevation of instruments: Anemometer above ground.	Pressure in inches: Station, reduced to mean of 24 hours.	Pressure in inches: Sea level, reduced to mean of 24 hours.	Pressure in inches: Departure from normal.	Temperature: Mean max.+mean min.÷2.	Temperature: Departure from normal.	Temperature: Maximum.	Temperature: Date.	Temperature: Mean maximum.	Temperature: Minimum.	Temperature: Date.	Temperature: Mean minimum.	Temperature: Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation: Total.	Precipitation: Departure from normal.	Precipitation: Days with 0.01 or more.	Wind: Total movement, miles.	Wind: Prevailing direction.	Wind: Maximum velocity: Miles per hour.	Wind: Maximum velocity: Direction.	Wind: Maximum velocity: Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
Northern Slope.							**47.3**	**+ 2.6**										**70**	**1.67**	**+ 0.4**										**5.4**		
Havre	2,505	11	44	27.33	29.99	+0.01	46.2	+ 2.6	79	16	57	25	29	35	41	41	38	80	2.82	+ 2.3	12	5,568	sw.	32	sw.	2	9	9	13	6.3	9.4	....
Helena	4,110	87	114	25.82	30.05	+ .02	44.6	+ 0.6	71	16	53	20	8	36	29	39	35	77	2.08	+ 1.3	11	4,795	sw.	32	sw.	18	9	6	16	6.3	13.1	....
Kalispell	2,962	11	34	26.95	30.04	+ .03	43.2	+ 0.7	68	1	51	28	24	36	29	39	37	85	3.40	+ 2.2	14	1,884	sw.	16	sw.	19	6	7	18	6.9	1.1	....
Miles City	2,371	26	48	27.49	30.06	+ .06	51.2	+ 4.7	84	15	64	30	13	38	43	43	39	74	1.96	+ 1.2	6	3,139	s.	20	nw.	4	16	9	6	4.2	.....	....
Rapid City	3,259	50	58	26.63	30.06	+ .05	51.2	+ 4.6	83	1	63	27	14	39	39	42	34	60	1.65	+ 0.6	4	5,953	w.	31	s.	21	13	6	12	5.0	T.	....
Cheyenne	6,088	84	101	24.05	30.02	+ .01	47.6	+ 2.3	74	16	59	25	14	36	38	38	31	60	1.29	+ 0.6	7	8,187	w.	40	w.	4	12	11	8	4.9	0.2	....
Lander	5,372	60	68	24.68	30.06	+ .02	47.2	+ 5.1	76	1	62	25	4	32	43	37	29	57	0.42	− 0.6	6	3,143	sw.	33	sw.	10	10	13	8	5.0	.....	....
Sheridan	3,790	10	47	26.13	30.06	......	46.6	......	81	16	63	21	26	30	51	37	31	67	0.65	......	4	3,206	s.	27	nw.	3	10	9	12	5.1	T.	....
Yellowstone Park	6,200	11	48	23.91	30.07	+ .05	42.0	+ 0.5	68	15	53	22	7	31	36	35	31	73	1.51	+ 0.4	12	5,165	s.	36	s.	2	9	9	13	5.8	T.	....
North Platte	2,821	11	51	27.13	30.07	+ .05	53.4	+ 3.4	87	17	68	26	15	39	50	44	38	70	0.92	− 0.2	4	5,416	n.	25	n.	23	15	7	9	4.1	.....	....
Middle Slope.							**57.4**	**+ 1.8**										**66**	**1.75**	**+ 0.3**										**4.3**		
Denver	5,291	129	172	24.76	30.02	+ .01	53.2	+ 2.2	79	3	67	30	14	40	39	42	32	53	3.05	+ 2.1	6	5,500	sw.	38	nw.	4	16	11	4	3.5	0.8	....
Pueblo	4,685	80	86	25.32	30.01	+ .02	53.6	+ 1.3	83	17	69	38	25	14	51	42	34	56	1.66	+ 1.0	4	3,969	nw.	29	nw.	4	15	13	3	3.4	T.	....
Concordia	1,398	42	50	28.57	30.05	+ .02	58.6	+ 3.2	83	6	69	23	27	48	40	50	46	74	2.49	+ 0.5	5	5,288	s.	24	se.	3	11	7	13	5.3	.....	....
Dodge	2,509	11	51	27.45	30.05	+ .03	57.8	+ 3.1	87	6	71	24	27	44	46	48	42	67	0.43	− 1.0	5	8,057	s.	33	nw.	11	18	8	5	3.7	.....	....
Wichita	1,358	139	158	28.59	30.02	− .01	59.3	+ 0.5	80	8	68	28	27	50	31	53	49	74	1.38	− 0.9	9	9,157	s.	42	n.	9	14	8	9	4.5	.....	....
Oklahoma	1,214	10	47	28.76	30.05	+ .02	61.6	+ 0.3	88	9	71	28	27	52	43	54	50	74	1.50	− 0.3	4	9,719	s.	36	n.	26	10	8	13	5.6	.....	....
Southern Slope.							**62.6**	**+ 0.2**										**66**	**4.64**	**+ 2.7**										**4.8**		
Abilene	1,738	10	52	28.22	30.02	+ .01	63.8	− 0.4	92	9	75	33	27	52	41	55	51	73	4.08	+ 1.8	5	6,226	s.	25	s.	4	10	9	12	5.3	.....	....
Amarillo	3,676	10	49	26.35	30.02	+ .02	58.0	+ 1.9	86	17	71	30	27	45	41	48	43	71	4.46	+ 2.8	7	8,184	s.	30	s.	6	14	9	8	4.9	.....	....
Del Rio	944	64	71	28.99	29.97	− .01	70.0	+ 0.1	93	9	80	44	15	60	36	....	....	....	6.67	+ 4.7	7	6,595	se.	39	se.	20	10	12	9	4.7	.....	....
Roswell	3,566	75	85	26.40	30.00	+ .04	58.4	− 1.1	86	2	72	32	28	44	44	46	35	53	3.37	+ 1.8	7	5,118	s.	26	nw.	19	14	9	8	4.2	.....	....
Southern Plateau.							**60.1**	**+ 0.3**										**54**	**1.36**	**+ 0.7**										**2.8**		
El Paso	3,672	110	133	26.20	29.93	+ .01	63.5	+ 1.1	88	11	75	43	28	52	34	50	39	49	0.80	− 0.2	5	7,064	se.	48	s.	3	16	12	3	3.6	.....	....
Santa Fe	7,013	57	62	23.31	30.01	+ .05	49.4	− 0.6	73	1	60	31	23	39	28	39	32	61	2.40	+ 1.3	10	4,764	se.	29	se.	3	20	6	5	3.5	.....	....
Flagstaff	6,908	8	57	......	......	......	45.6	+ 0.9	69	13	59	26	27	32	42	38	....	....	1.73	......	6	......	e.	36	ne.	23	16	9	6	....	.....	....
Phoenix	1,108	76	81	28.73	29.88	.00	71.2	+ 1.0	96	1	84	50	23	59	36	58	48	49	2.30	+ 2.0	5	3,895	e.	25	w.	21	21	5	5	2.5	.....	....
Yuma	141	9	58	29.71	29.86	+ .01	73.6	+ 1.2	99	1	88	49	23	60	38	60	51	53	0.89	+ 0.7	3	3,204	ne.	22	w.	21	27	2	2	1.2	.....	....
Independence	3,910	11	12	25.95	29.92	− .03	57.2	− 2.1	82	14	72	38	13	42	42	47	40	59	0.03	− 0.3	1	4,017	se.	33	se.	2	19	8	4	3.4	.....	....
Middle Plateau.							**51.9**	**+ 1.4**										**56**	**1.59**	**+ 0.7**										**3.8**		
Reno	4,532	74	81	25.47	29.97	......	51.8	+ 2.1	80	15	67	27	22	37	43	43	33	54	0.16	− 0.2	3	4,214	w.	31	w.	19	16	9	6	3.6	.....	....
Tonopah	6,090	12	20	24.08	29.95	......	53.2	......	73	13	62	31	22	44	24	42	32	46	0.00	− 0.8	0	6,269	se.	36	nw.	3	20	7	4	3.1	.....	....
Winnemucca	4,344	18	56	25.62	30.01	− .04	50.2	+ 1.6	83	14	66	24	4	35	44	41	33	60	0.63	+ 1.1	6	4,181	ne.	28	sw.	19	15	5	11	4.5	.....	....
Modena	5,479	10	43	24.64	29.98	+ .02	49.9	− 0.2	73	1	66	29	5	34	41	40	30	53	0.30	− 0.5	3	7,401	w.	50	s.	2	18	10	3	2.9	.....	....
Salt Lake City	4,360	147	189	25.63	29.99	− .02	55.8	+ 3.6	76	1	65	35	4	46	27	47	41	62	2.61	+ 1.2	8	5,552	se.	37	e.	24	14	7	10	4.9	.....	....
Durango	6,546	10	......	......	......	......	48.6	− 0.3	78	12	63	28	5	34	46	....	....	....	5.55	+ 3.8	6	......	nw.	....	....	....	20	6	5	....	.....	....
Grand Junction	4,602	82	96	25.42	30.00	+ .01	53.6	+ 0.3	74	20	65	35	31	42	33	45	38	61	1.89	+ 1.0	6	5,028	e.	35	w.	8	15	10	6	3.9	.....	....
Northern Plateau.							**52.0**	**+ 2.6**										**68**	**1.59**	**+ 0.5**										**5.7**		
Baker	3,471	48	53	26.45	30.04	− .04	49.4	+ 3.9	79	15	61	30	11	38	35	42	35	64	1.14	+ 0.2	7	4,980	se.	27	s.	16	9	14	8	4.8		
Boise	2,739	78	86	27.18	30.04	− .02	54.4	+ 4.1	83	14	65	34	4	44	37	46	39	61	1.20	− 0.1	10	3,195	nw.	25	se.	19	12	7	12	5.3	.....	....
Lewiston	757	40	48	29.18	29.99	− .08	53.7	+ 1.9	78	14	64	36	7	43	33	....	....	....	1.71	+ 0.5	12	1,604	e.	19	w.	4	10	6	15	6.0	.....	..
Pocatello	4,477	46	54	25.50	30.02	− .02	50.4	+ 2.4	77	15	61	35	23	40	36	43	37	68	2.02	+ 1.0	8	4,730	se.	28	s.	19	9	7	15	5.6		....
Spokane	1,929	101	110	27.95	30.01	− .05	49.6	+ 2.3	73	16	59	32	23	40	33	45	41	74	1.48	0.0	13	3,704	ne.	26	s.	18	5	11	15	6.7	.....	....
Walla Walla	1,000	57	65	28.92	30.00	− .07	54.4	+ 0.7	83	16	63	39	24	46	35	48	44	72	1.99	+ 0.5	13	2,751	s.	19	se.	18	10	6	15	6.0	.....	....
North Pacific Coast Region.							**54.5**	**+ 3.4**										**84**	**6.55**	**+ 2.6**										**7.3**		
North Head	211	11	56	29.71	29.93	− .12	55.6	+ 2.7	72	27	59	47	20	52	20	53	51	87	7.90	+ 4.0	18	13,271	se.	78	se.	16	5	6	20	7.5	.....	....
Port Crescent	259	8	53	29.64	29.92	− .10	49.8	+ 2.4	66	14	57	33	3	43	21	....	....	....	6.00	+ 2.5	15	3,570	s.	15	se.	18	2	8	21	8.0	.....	....
Seattle	125	215	250	29.82	29.95	− .10	54.6	+ 3.8	71	13	61	43	22	49	24	52	49	83	4.37	+ 1.5	14	5,259	se.	39	sw.	18	4	2	25	7.8	.....	....
Tacoma	213	113	120	29.73	29.95	− .09	54.2	+ 3.6	72	13	61	37	22	47	27	51	49	83	4.98	+ 1.6	13	2,912	sw.	25	sw.	18	4	9	18	7.5	.....	....
Tatoosh Island	109	7	57	29.78	29.87	− .14	53.8	+ 3.9	65	27	57	45	1	50	14	52	51	91	15.60	+ 7.6	21	13,401	e.	56	sw.	18	2	7	22	8.2	.....	....
Portland, Oreg.	153	68	106	29.79	29.95	− .11	57.4	+ 4.1	72	14	64	43	22	51	26	53	50	79	3.47	− 0.2	14	3,794	se.	27	sw.	18	8	10	13	6.5	.....	....
Roseburg	510	9	57	29.42	29.97	− .11	56.3	+ 3.5	75	14	65	39	22	47	26	51	48	79	3.56	+ 1.0	13	1,551	s.	20	w.	9	1	23	7	5.8	.....	....
Middle Pacific Coast Region.							**59.3**	**+ 0.6**										**70**	**1.52**	**0.0**										**4.1**		
Eureka	62	73	89	29.94	30.01	− .05	54.8	+ 1.7	67	8	62	42	22	48	20	52	50	87	3.79	+ 1.1	13	4,224	se.	36	sw.	9	12	9	10	5.2	.....	....
Mount Tamalpais	2,375	11	18	27.54	30.01	.00	56.2	− 2.5	80	14	61	43	1	51	17	49	42	66	2.18	+ 0.3	9	11,444	nw.	72	nw.	17	20	4	7	3.9	.....	....
Point Reyes Light	490	7	18	29.45	29.97	......	56.8	+ 2.1	76	14	61	49	5	53	21	....	....	....	1.53	......	10	12,127	nw.	49	s.	17	13	6	12	5.0	.....	....
Red Bluff	332	50	56	29.60	29.96	− .07	62.2	− 1.6	90	14	74	43	22	50	38	53	45	60	1.56	0.0	6	3,268	nw.	23	se.	19	16	5	10	4.2	.....	....
Sacramento	69	106	117	29.90	29.97	− .04	62.2	0.0	86	14	74	40	22	51	34	54	47	64	0.82	− 0.2	4	4,787	s.	22	sw.	9	23	4	4	2.9	.....	....
San Francisco	155	209	213	29.82	29.99	− .02	62.0	+ 3.6	89	14	69	50	22	55	35	55	51	74	0.29	− 1.0	3	3,861	w.	30	sw.	28	16	9	6	4.0	.....	....
San Jose	141	12	110	29.84	30.00	......	60.8	+ 0.5	90	14	74	39	22	48	42	....	....	....	0.50	− 0.4	3	3,830	nw.	24	sw.	9	20	5	6	3.2	.....	....
South Pacific Coast Region.							**65.8**	**+ 3.5**										**64**	**0.42**	**− 0.4**										**3.2**	.....	....
Fresno	327	89	98	29.61	29.97	+ .01	64.6	− 0.1	92	14	78	43	22	52	39	53	44	54	0.26	− 0.5	4	4,495	nw.	25	nw.	3	21	6	4	2.8	.....	....
Los Angeles	338	159	191	29.58	29.94	− .01	68.6	+ 6.3	97	13	78	54	22	59	34	57	51	62	0.31	− 0.5	3	3,996	s.	18	s.	26	19	4	8	3.2	.....	....
San Diego	87	62	70	29.83	29.92	− .03	66.0	+ 3.0	90	25	73	54	23	59	28	59	55	74	1.05	+ 0.6	5	4,074	nw.	20	nw.	23	16	11	4	3.6	.....	....
San Luis Obispo	201	32	40	29.77	29.99	.00	64.2	+ 5.0	98	13	77	42	5	51	47	54	47	64	0.08	− 1.2	3	2,454	nw.	15	w.	19	20	6	5	3.2	.....	....
West Indies.																																
San Juan	82	8	54	29.86	29.94	+ .04	80.2	......	91	13	86	70	22	74	16	....	....	....	4.34	− 1.8	12	5,843	s.	30	e.	1	15	13	3	4.1	.....	....
Panama.																																
Balboa Heights *	118	6	69	29.75	29.85	......	79.7	......	90	14	86	70	1	74	18	75	75	93	6.44	− 4.1	20	4,357	nw.	27	s.	7	0	10	21	8.1	.....	....
Colon	10	5	71	29.84	29.85	......	79.8	......	91	4	84	73	11	76	15	76	75	89	22.16	+ 6.0	22	5,074	se.	26	w.	15	5	9	17	6.9	.....	....

* Formerly Ancon; station moved to Balboa Heights Oct. 1, 1914. Culebra meterological station discontinued Sept. 12, 1914.

TABLE II.—*Accumulated amounts of precipitation for each five minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any five minutes, or 0.80 in one hour, during October, 1914, at all stations furnished with self-registering gages.*

Stations.	Date.	Total duration. From—	Total duration. To—	Total amount of precipitation.	Excessive rate. Began—	Excessive rate. Ended—	Amount before excessive rate began.	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Abilene, Tex.	12	D. N. a. m.	D. N. a. m.	1.05	3.33 a.m.	4.00 a. m.	0.01	0.20	0.61	0.82	0.89	0.96	1.00								
Albany, N. Y.	19			0.37														0.10			
Alpena, Mich.	17			0.90														.34			
Amarillo, Tex.	22-23	6.30 p. m.	7.43 a. m.	2.16	8.45 p. m.	9.17 p. m.	.13	.22	.41	.56	.64	.69	.77	.79							
Anniston, Ala.	10	6.40 a. m.	10.00 a. m.	0.76	7.55 a. m.	8.20 a. m.	.19	.09	.19	.29	.40	.51									
Asheville, N. C.	13	2.55 p. m.	4.15 p. m.	0.66	2.57 p. m.	3.15 p. m.	.01	.09	.32	.50	.56										
Atlanta, Ga.	14-15	7.45 p. m.	11.40 a. m.	3.30	2.21 a. m.	3.20 a. m.	.39	.17	.33	.42	.50	.60	.71	.90	1.02	1.13	1.24	1.48			
Atlantic City, N. J.	16			1.52														.39			
Augusta, Ga.	14	3.20 p. m.	6.50 p. m.	0.69	3.28 p. m.	3.41 p. m.	.04	.17	.46	.56											
Baker, Oreg.	17			0.38														.20			
Baltimore, Md.	16			1.04														.27			
Bentonville, Ark.	20-21	10.15 p. m.	2.40 a. m.	1.56	12.52 a. m.	1.52 a. m.	.43	.13	.29	.41	.44	.48	.55	.57	.58	.62	.78	1.05			
Binghamton, N. Y.	16			1.10														.42			
Birmingham, Ala.	10	5.28 p. m.	6.35 p. m.	0.85	5.30 p. m.	6.00 p. m.	.01	.12	.37	.49†	.60†	.71†	.80†								
Bismarck, N. Dak.	22			0.42														.12			
Block Island, R. I.	17			0.90														.35			
Boise, Idaho.	1			0.19														.17			
Boston, Mass.	17			0.76														.18			
Buffalo, N. Y.	9			0.39														.23			
Burlington, Vt.	17			0.54														.07			
Cairo, Ill.	9	10.50 a. m.	12.15 p. m.	0.60	11.07 a. m.	11.17 a. m.	.04	.23	.44												
Canton, N. Y.	18			0.42														.30			
Charles City, Iowa.	9	3.17 p. m.	4.50 p. m.	0.59	3.41 p. m.	3.58 p. m.	.14	.06	.26	.35	.42										
Charleston, S. C.	2			2.36														.55			
Charlotte, N. C.	4			1.25														.54			
Chattanooga, Tenn.	10	12.10 p. m.	2.29 p. m.	0.51	12.33 p. m.	12.50 p. m.	.01	.14	.24	.36	.41										
Cheyenne, Wyo.	21			0.69														.27			
Chicago, Ill.	16			0.75														.37			
Cincinnati, Ohio.	15			1.59														.42			
Cleveland, Ohio.	18			0.73														.38†			
Columbia, Mo.	7	6.15 p. m.	10.00 p. m.	1.40	8.31 p. m.	9.05 p. m.	.26	.15	.33	.40	.52	.77	.91	1.00							
	9-10	8.40 p. m.	D. N. a. m.	1.21	10.25 p. m.	11.10 p. m.	.19	.31	.41	.43	.54	.67	.75	.79	.86	.91					
Columbia, S. C.	14			0.55														.29			
Columbus, Ohio.	8			0.64														.36			
Concord, N. H.	29			0.31														.31			
Concordia, Kans.	9	12.51 p. m.	1.53 p. m.	0.99	12.58 p. m.	1.16 p. m.	.01	.15	.65	.84	.90										
Corpus Christi, Tex.	23-24	6.57 p. m.	7.35 a. m.	3.54	10.35 p. m.	10.54 p. m.	.31	.14	.36	.50	.57										
					11.34 p. m.	12.49 a. m.	1.05	.10	.17	.20	.32	.38	.44	.50	.60	.68	.76	.86	1.04		
Davenport, Iowa.	10			0.43														.20			
Dayton, Ohio.	14			1.08														.47			
Del Rio, Tex.	12	4.55 p. m.	6.55 p. m.	1.12	4.55 p. m.	5.46 p. m.	.00	.10	.29	.55	.71	.77	.81	.86	.88	.94	1.04	1.11			
	20	5.50 p. m.	9.15 p. m.	1.06	5.50 p. m.	6.43 p. m.	.00	.19	.36	.49	.50	.53	.55	.59	.60	.65	.87	.98			
	24-25	2.50 p. m.	12.50 a. m.	2.52	5.36 p. m.	6.56 p. m.	.25	.07	.18	.36	.43	.53	.79	1.04	1.18	1.24	1.31	1.55	1.94		
Denver, Colo.	22			0.91														.63			
Des Moines, Iowa.	7	6.36 a. m.	3.37 p. m.	0.92	1.20 p. m.	1.39 p. m.	.21	.14	.26	.42	.55										
Detroit, Mich.	10			0.80														.41			
Devils Lake, N. Dak.	8			0.44														.17			
Dodge City, Kans.	11			0.21														.21			
Dubuque, Iowa.	23			0.30														.30			
Duluth, Minn.	10			0.67														.22			
Durango, Colo.																					
Eastport, Me.	19			0.52														.16			
Elkins, W. Va.	24			0.53														.17			
El Paso, Tex.	20			0.61														.45			
Erie, Pa.	9			0.51														.24			
Escanaba, Mich.	7			0.19														.11			
Eureka, Cal.	18-19			1.07														.35			
Evansville, Ind.	10	4.10 a. m.	6.05 a. m.	0.69	4.20 a. m.	4.44 a. m.	.03	.09	.18	.36	.44	.48									
Flagstaff, Ariz.																					
Fort Smith, Ark.	20	11.47 a. m.	1.22 p. m.	0.45	12.42 p. m.	12.50 p. m.	.04	.19	.40												
Fort Wayne, Ind.	10	D. N. a. m.	8.55 a. m.	1.40	6.14 a. m.	7.25 a. m.	.09	.06	.18	.36	.44	.50	.55	.62	.68	.73	.79	.83	1.15		
Fort Worth, Tex.	12			0.11														.09			
Frenso, Cal.	29			0.15														.06			
Galveston, Tex.	22			0.75														.34			
Grand Haven, Mich.	16			0.87														.38			
Grand Junction, Colo.	22			0.49														.30			
Grand Rapids, Mich.	10			1.44														.71			
Green Bay, Wis.	7			0.32														.18			
Hannibal, Mo.	7-8	3.22 p. m.	9.58 a. m.	2.75	8.46 p. m.	9.11 p. m.	.82	.08	.12	.34	.67	.80									
Harrisburg, Pa.	7			0.32														.26			
Hartford, Conn.	19			0.43														.33			
Hatteras, N. C.	3-4	D. N. p. m.	D. N. a. m.	0.64	10.24 p. m.	10.52 p. m.	.03	.07	.16	.30	.40	.43	.50								
Havre, Mont.	3-4			1.32														(*)			
Helena, Mont.	4-5			1.00														(*)			
Houghton, Mich.	10			0.41														.27			
Houston, Tex.	12	11.56 a. m.	3.27 p. m.	1.21	12.59 p. m.	1.23 p. m.	.47	.13	.26	.39	.55	.61									
Huron, S. Dak.	9			0.56														.24			
Independence, Cal.	1			0.03														.03			
Indianapolis, Ind.	9-10	10.30 p. m.	7.20 a. m.	0.85	5.24 a. m.	5.44 a. m.	.07	.19	.32	.41	.55										
Iola, Kans.	9	6.18 p. m.	8.50 p. m.	1.13	7.10 p. m.	7.35 p. m.	.04	.14	.19	.36	.69	.92									
Jacksonville, Fla.	4	11.13 a. m.	2.20 p. m.	0.84	12.18 p. m.	12.37 p. m.	.09	.06	.22	.46	.56										
Kalispell, Mont.	1			0.54														.32			
Kansas City, Mo.	8	4.05 a. m.	9.15 a. m.	0.96	4.14 a. m.	4.43 a. m.	.03	.08	.21	.33	.42	.50	.57								
	9-10	7.04 p. m.	D.N. a. m.	2.22	7.52 p. m.	8.44 p. m.	.16	.13	.28	.51	.85	.90	.99	1.35	1.60	1.73	1.78	1.84			
Keokuk, Iowa.	7			0.70														.28			
Key West, Fla.	1-2	6.55 p. m.	D. N a. m.	1.62	7.02 p. m.	7.58 p. m.	.01	.15	.25	.36	.53	.73	.91	1.05	1.09	1.19	1.32	1.35			
	3	4.57 a. m.	7.30 a. m.	1.82	5.53 a. m.	7.02 a. m.	.18	.16	.35	.56	.72	.85	.93	.97	1.07	1.11	1.19	1.48	1.64		
	17	D. N. a. m.	12.10 p. m.	1.02	6.03 a. m.	6.26 a. m.	.13	.05	.10	.15	.36	.53									
Knoxville, Tenn.	15			2.06														.39			
La Crosse, Wis.	6			0.93														.48			
Lander, Wyo.	22			0.19														.05			
Lansing, Mich.	16			1.79														.32			
Lewiston, Idaho.	30			0.25														.16			
Lexington, Ky.	10	3.30 p. m.	3.55 p. m.	0.62	3.42 p. m.	3.49 p. m.	.02	.35	.60												
Lincoln, Nebr.																					
Little Rock, Ark.	9	7.58 a. m.	8.55 a. m.	0.73	8.02 a. m.	8.36 a. m.	.01	.12	.18	.24	.40	.50	.62	.67							
Los Angeles, Cal.	3			0.19														.04			
Louisville, Ky.	10			0.31														.25			
Ludington, Mich.	10	D. N. a. m.	D. N. a. m.	0.62	2.08 a. m.	2.28 a. m.	.02	.21	.32	.41	.47										
Lynchburg, Va.	15-16	10.00 a. m.	D. N. a. m.	1.37	1.10 a. m.	1.33 a. m.	.78	.11	.26	.39	.46	.52									

TABLE II.—*Accumulated amounts of precipitation for each five minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any five minutes, or 0.80 in one hour, during October, 1914, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.													
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Macon, Ga.	6			0.50														0.37			
Madison, Wis.	23			0.30														.29			
Marquette, Mich.	23			0.21														.16			
Memphis, Tenn.	20			0.81														.34			
Meridian, Miss.	13			0.83														.55			
Miami, Fla.	4	9.40 a.m.	2.10 p.m.	1.48	11.18 a.m.	12.09 p.m.	0.04	0.02	0.20	0 22	0.24	0.29	0.33	0.46	0.65	0.80	0.90	.96			
	14	7.38 a.m.	8.24 a.m.	0.57	7.46 a.m.	8.11 a.m.	.01	.09	.20	.28	.37	.51									
	25-26	D.N.p.m.	D. N. a.m.	0.72	11.14 p.m.	11.42 p.m.	.04	.25	.35	.43	.49	.53	.59								
Milwaukee, Wis.	16			2.30														.41			
Minneapolis, Minn.	6-7	11.03 p.m.	D. N. a.m.	0.44	11.26 p.m.	11.42 p.m.	.02	.05	.17	.40	.41										
Mobile, Ala.	5			0.28														.28			
Modena, Utah.	3			0.26														.10			
Montgomery, Ala.	1-2	9.10 p.m.	7.55 a.m.	1.87	2.20 a.m.	2.47 a.m.	.85	.06	.13	.21	.38	.56	.62								
Moorhead, Minn.	8			0.45														.40			
Mount Tamalpais, Cal.	17			0.63														.28			
Mount Weather, Va.	15			0.81														.42			
Nantucket, Mass.	17			0.50														.28			
Nashville, Tenn.	9	12.45 p.m.	3.35 p.m.	0.54	2.28 p.m.	2.48 p.m.	.04	.26	.27	.36	.41										
New Haven, Conn.	16			2.71														.38			
New Orleans, La.	11	9.20 a.m.	11.55 a.m.	1.81	9.20 a.m.	9.50 a.m.	.00	.07	.39	.93	1.37	1.58	1.72								
	13	2.49 p.m.	4.39 p.m.	0.57	2.52 p.m.	3.06 p.m.	.01	.24	.44	.54											
New York, N. Y.	16			1.70														.36			
Norfolk, Va.	11-12	9.55 p.m.	D. N. a.m.	0.82	10.35 p.m.	10.54 p.m.	.04	.10	.38	.67	.74										
Northfield, Vt.	17			0.61														.09			
North Head, Wash.	20			1.84														.35			
North Platte, Nebr.	4			0.70														.29			
Oklahoma, Okla.	6			0.73														.49†			
Omaha, Nebr.	7	9.20 p.m.	D. N. p.m.	0.68	9.27 p.m.	9.56 p.m.	.01	.10	.27	.40	.48	.54	.58								
Oswego, N. Y.	9.10			0.54														(*)			
Palestine, Tex.	12	12.50 p.m.	1.40 p.m.	0.83	12.55 p.m	1.16 p.m.	.01	.08	.15	.35	.77	.81									
Parkersburg, W. Va.	13			0.80														.40			
Pensacola, Fla.	11			0.68														.68			
Peoria, Ill.	16			0.63														.40			
Philadelphia, Pa.	16			1.33														.38			
Phoenix, Ariz.	30			0.67														.37			
Pierre, S. Dak.	22			0.38														.20			
Pittsburgh, Pa.	10	3.13 p.m.	3.40 p.m.	0.29	3.13 p.m.	3.18 p.m.	.00	.26													
Pocatello, Idaho.	3			0.75														.15			
Point Reyes Light, Cal.	17			0.59														.26			
Port Huron, Mich.	10			0.97														.34			
Portland, Me.	19			1.06														.28			
Portland, Oreg.	1			0.75														.21			
Providence, R. I.	17			1.50														.36			
Pueblo, Colo.	23-24			1.43														.15			
Raleigh, N. C.	11			0.30														.16			
Rapid City, S. Dak.	22			0 86														.30			
Reading, Pa.	16			1.02														.17			
Red Bluff, Cal.	9			0.46														.41†			
Reno, Nev.	29			0.12														.04			
Richmond, Va.	16			0.53														.31			
Rochester, N. Y.	9			0.43														.39			
Roseburg, Oreg.	18			1.38														.35			
Roswell, N. Mex.	21			1.25														.55			
Sacramento, Cal.	29			0.29														.16			
Saginaw, Mich.	16			1.22														.33			
St. Joseph, Mo.	8	4.16 p.m.	4.36 p.m.	0.32	4.16 p.m.	4.21 p.m.	.00	.30													
St. Louis, Mo.	8	11.38 a.m.	6.40 p.m.	1.33	1.00 p.m.	1.32 p.m.	.27	.09	.26	.36	.44	.51	.60	.64							
St. Paul, Minn.	10	1.15 a.m.	4.00 a.m.	0.57	1.18 a.m.	1.30 a.m.	.02	.07	.29	.36											
Salt Lake City, Utah.	9			0.71														.17			
San Antonio, Tex.	23	1.40 a.m.	11.30 a.m.	4.62	7.06 a.m.		.24	.07	.27	.46	.60	.67	.70	.75	.78	.87	.95				
								1.02	1.05	1.12	1.16	1.18	1.31	1.45	1.47	1.50	1.52				
								1.55	1.62	1.67	1.72	1.78	1.91	2.25	2.42	2.67	2.75				
						10.23 a.m.		2.83	2.98	3.20	3.51	3.60	3.67	3.77	3.99	4.08	4.14				
San Diego, Cal.	3			0.55														.14			
Sand Key, Fla.	1	6.40 p.m.	9.37 p.m.	2.24	7.47 p.m.	8.47 p.m.	.32	.16	.22	.33	.54	.88	1.12	1.23	1.33	1.49	1.66	1.80			
	3	1.21 a.m.	5.55 p.m.	3.19	2.36 a.m.	2.51 a.m.	.04	.08	.40	.66											
					5.49 a.m.	6.49 a.m.	.91	.23	.60	.84	.94	1.00	1.09	1.31	1.43	1.50	1.58	1.79			
	17	4.00 a.m.	12.00 m.	2.18	4.48 a.m.	5.30 a.m.	.03	.07	.22	.47	.79	.97	1.16	1.39	1.54	1.57					
Sandusky, Ohio.	8			0.29														.17			
San Francisco, Cal.	17			0.25														.08			
San Jose, Cal.	17			0.36														.22			
San Luis Obispo, Cal.	29			0.04														.03			
Santa Fe, N. Mex.	4			0.37														.29			
Sault Ste. Marie, Mich.	10			0.65														.24			
Savannah, Ga.	2	D. N. a.m.	5.15 p.m.	2.80	10.34 a.m.	11.45 a.m.	.52	.05	.12	.16	.21	.30	.41	.55	.60	.73	.83	.98	1.18		
	6	10.21 a.m.	1.20 p.m.	2.13	11.47 a.m.	12.28 p.m.	.07	.05	.22	.48	.63	.79	1.29	1.73	1.93	2.03					
		3.40 p.m.	5.15 p.m.	1.56	3.51 p.m.	4.31 p.m.	.01	.63	.99	1.16	1.22	1.27	1.32	1.45	1.52						
Scranton, Pa.	16			0.66														.11			
Seattle, Wash.	30			0.60														.29			
Sheridan, Wyo.	3			0.34														.14			
Shreveport, La.	19			0.12														.07			
Sioux City, Iowa.	6	6.45 p.m.	8.30 p.m.	0.63	7.45 p.m.	7.55 p.m.	.07	.26	.55												
	9	7.05 p.m.	8.00 p.m.	0.95	7.16 p.m.	7.36 p.m.	.01	.19	.54	.82	.91										
Spokane, Wash.	30			0.13														.12			
Springfield, Ill.	16			0.72														.33			
Springfield, Mo.	12			0.78														(*)			
Syracuse, N. Y.	16			0.66														.18			
Tacoma, Wash.	9			0.51														.17			
Tampa, Fla.	15	8.05 a.m.	12.25 p.m.	0.85	11.07 a.m.	11.39 a.m.	.10	.05	.10	.12	.27	.35	.61	.73							
	26	6.20 p.m.	10.30 p.m.	2.06	7.20 p.m.	8.14 p.m.	.09	.12	.16	.31	.52	.65	.73	.81	.98	1.12	1.23	1.30			
Tatoosh Island, Wash.	18	5.13 a.m.	12.50 p.m.	1.47	10.33 a.m.	10.56 a.m.	.20	.19	.38	.61	.88	1.00									
Taylor, Tex.	23	12.50 p.m.	4.05 p.m.	1.63	1.28 p.m.	2.49 p.m.	.01	.20	.42	.51	.64	.80	.89	.95	1.00	1.09	1.12	1.28	1.51	1.57	
Terre Haute, Ind.	10	D. N. a.m.	6.38 a.m.	1.17	2.44 a.m.	3.05 a.m.	.27	.11	.15	.17	.44	.47									
Thomasville, Ga.	4			0.49														.47			
Toledo, Ohio.	10			0.75														.24			
Tonopah, Nev.				(‡)																	
Topeka, Kans.	6			0.64														.62			
Valentine, Nebr.	11	9.45 a.m.	11.35 a.m.	0.59	10.47 a.m.	11.02 a.m.	0.14	.17	.31	.36											
Vicksburg, Miss.	2			0.68														.47			
Walla Walla, Wash.	10			0.45														.30			

TABLE II.—*Accumulated amounts of precipitation for each five minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any five minutes, or 0.80 in one hour, during October, 1914, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.													
		From—	To—		Began—	Ended.		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Washington, D. C.	16			1.09														0.46			
Wichita, Kans.	4			0.37														.32			
Williston, N. Dak.	4			0.23														.08			
Wilmington, N. C.	23-24	9.40 a. m.	D. N. a. m.	2.50	11.45 a. m.	12.19 p. m.	0.30	0.11	0.22	0.34	0.47	0.75	1.02	1.08							
Winnemucca, Nev.	20			0.27														.09			
Wytheville, Va.	15			1.27														.33			
Yankton, S. Dak.	4			0.34														.19			
Yellowstone Park, Wyo.	2-3			0.48														(*)			

* Self-register not working. † Record partly estimated. ‡ No precipitation occurred during month.

TABLE III.—*Data furnished by the Canadian Meteorological Service, October, 1914.*

Stations.	Pressure in inches.			Temperature.						Precipitation.		
	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max. + mean min. ÷ 2.	Departure from normal.	Mean maximum.	Mean minimum.	Highest.	Lowest.	Total.	Departure from normal.	Total snowfall.
	Inches.	*Inches.*	*Inches.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	*Inches.*	*Inches.*	*Inches.*
St. Johns, N. F.	29.74	29.88	−.03	42.4	− 3.0	49.2	35.7	66	24	5.65	+0.30	
Sydney, C. B. I.	29.95	29.99	+.03	46.7	+ 0.2	55.2	38.2	69	30	1.44	−3.25	
Halifax, N. S.	29.93	30.04	+.04	47.2	0.0	58.7	35.7	71	21	1.97	−3.58	
Yarmouth, N. S.	29.99	30.06	+.04	48.6	+ 1.0	55.4	41.9	67	30	2.79	−1.91	
Charlottetown, P. E. I.	29.96	30.00	+.04	47.6	+ 1.1	54.8	40.3	69	28	3.27	−1.63	T.
Chatham, N. B.	29.99	30.01	+.05	46.2	+ 3.2	55.7	36.8	78	18	3.49	−0.37	4.0
Father Point, Que.	29.96	29.98	+.03	40.8	+ 1.0	47.4	34.3	57	26	3.50	+0.60	2.3
Quebec, Que.	29.71	30.03	+.03	44.8	+ 2.4	51.9	37.7	68	23	5.17	+2.02	3.0
Montreal, Que.	29.85	30.06	+.05	49.0	+ 4.2	56.0	42.0	71	24	2.39	−0.74	0.6
Stonecliffe, Ont.	29.45	30.06	+.05	46.6	+ 3.8	57.8	35.5	78	20	2.19	−0.24	0.6
Ottawa, Ont.	29.80	30.13	+.12	48.7	+ 4.9	56.9	40.6	76	24	2.44	−0.11	0.6
Kingston, Ont.	29.77	30.08	+.05	51.2	+ 4.2	58.5	44.0	71	22	1.52	−1.21	T.
Toronto, Ont.	29.67	30.05	+.01	52.8	+ 6.2	61.4	44.1	79	26	1.53	+0.83	T.
White River, Ont.	28.71	30.04	+.06	41.8	+ 4.7	54.3	29.2	74	2	1.96	−0.39	1.0
Port Stanley, Ont.	29.41	30.05	.00	52.0	+ 4.2	60.3	43.6	70	23	1.86	−1.12	0.1
Southampton, Ont.	29.36			52.5	+ 6.4	61.2	43.8	74	25	2.39	−0.78	1.2
Parry Sound, Ont.	29.38	30.08	+.07	49.6	+ 5.7	58.9	40.3	75	18	2.37	−1.55	
Port Arthur, Ont.	29.32	30.03	+.05	46.5	+ 6.6	55.0	38.0	69	21	1.35	−1.21	T.
Winnipeg, Man.	29.13	29.96	−.02	51.0	+11.9	61.6	40.4	85	17	2.22	+0.52	
Minnedosa, Man.	28.14	29.96	−.01	47.8	+10.0	58.2	37.4	82	18	1.44	+0.24	T.
Qu'Appelle, Sask.	27.66	29.90	−.07	46.2	+ 6.8	56.6	35.9	77	9	1.43	+0.33	2.0
Medicine Hat, Alberta.	27.64	29.93	−.04	47.8	+ 3.0	58.0	37.5	80	28	3.48	+2.90	
Swift Current, Sask.	27.34	29.91	−.06	45.9	+ 3.8	56.7	35.1	81	26	2.49	+1.61	2.0
Calgary, Alberta.	26.36	29.90	−.05	44.6	+ 4.5	55.8	33.3	76	22	1.82	+1.34	18.2
Banff, Alberta.	25.35	29.96	+.01	41.4	+ 2.1	50.6	32.1	67	22	1.69	+0.67	1.8
Edmonton, Alberta.	27.60	29.90	−.03	43.3	+ 2.2	54.6	32.1	68	23	1.07	+0.37	
Prince Albert, Sask.	28.36	29.93	−.04	41.0	+ 3.9	48.5	33.6	64	17	1.37	+0.54	
Battleford, Sask.	28.20	29.94	−.03	46.2	+ 6.6	56.7	35.6	75	24	2.26	+1.81	
Kamloops, B. C.	28.70	29.92	−.04	49.9	+ 2.9	58.4	41.5	68	29	0.79	+0.18	
Victoria, B. C.	29.66	29.91	−.10	52.7	+ 3.5	58.0	47.5	67	42	2.58	+0.21	
Barkerville, B. C.	25.58	29.86	−.08	41.7	+ 2.0	50.8	32.6	59	21	2.19	−0.51	
Hamilton, Bermuda.	29.92	30.08	+.06	72.4	− 0.6	78.2	66.7	80	61	4.08	−2.63	

Chart I. Hydrographs of Several Principal Rivers, October, 1914.

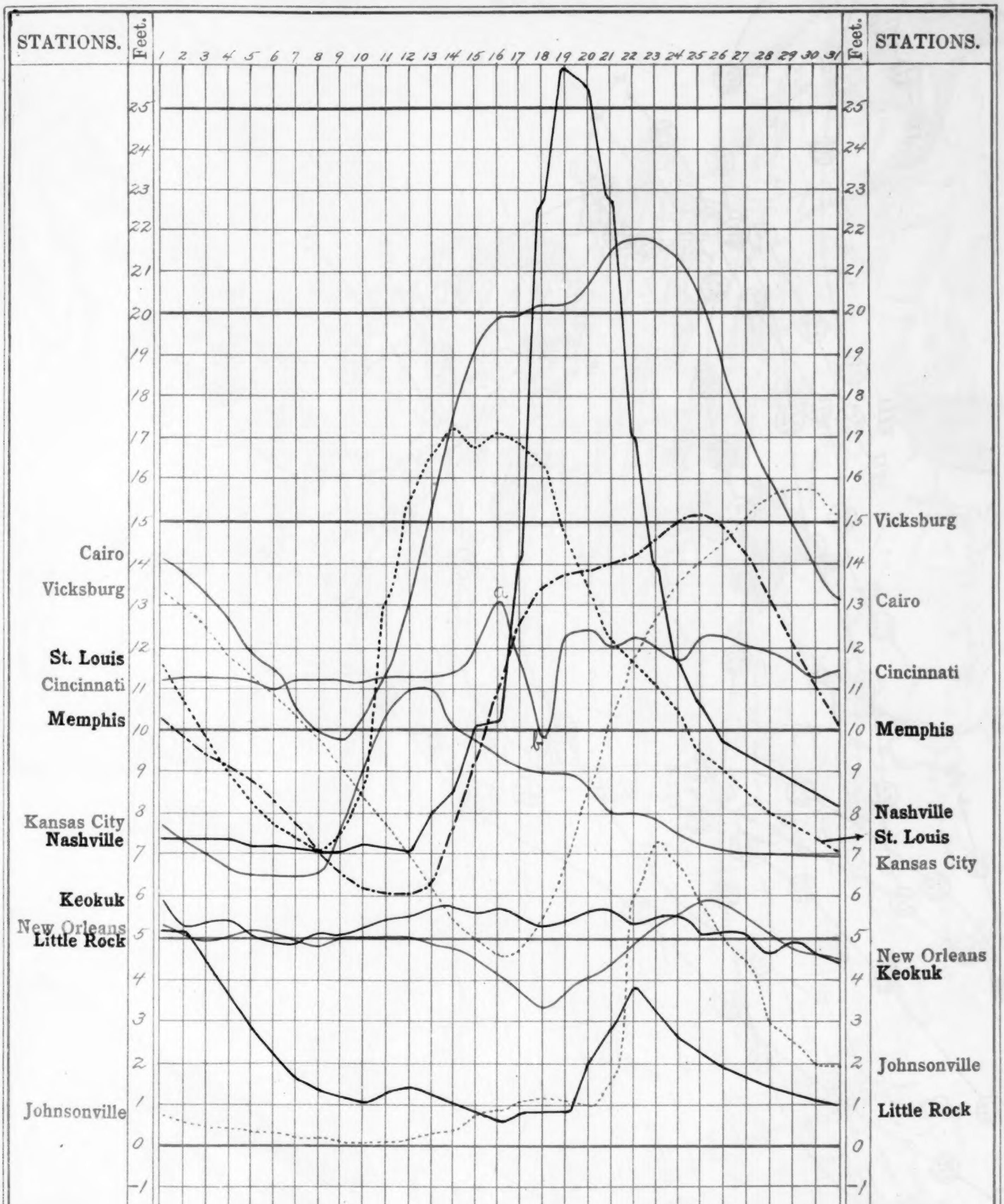

Chart II. Tracks of Centers of High Areas, October, 1914.

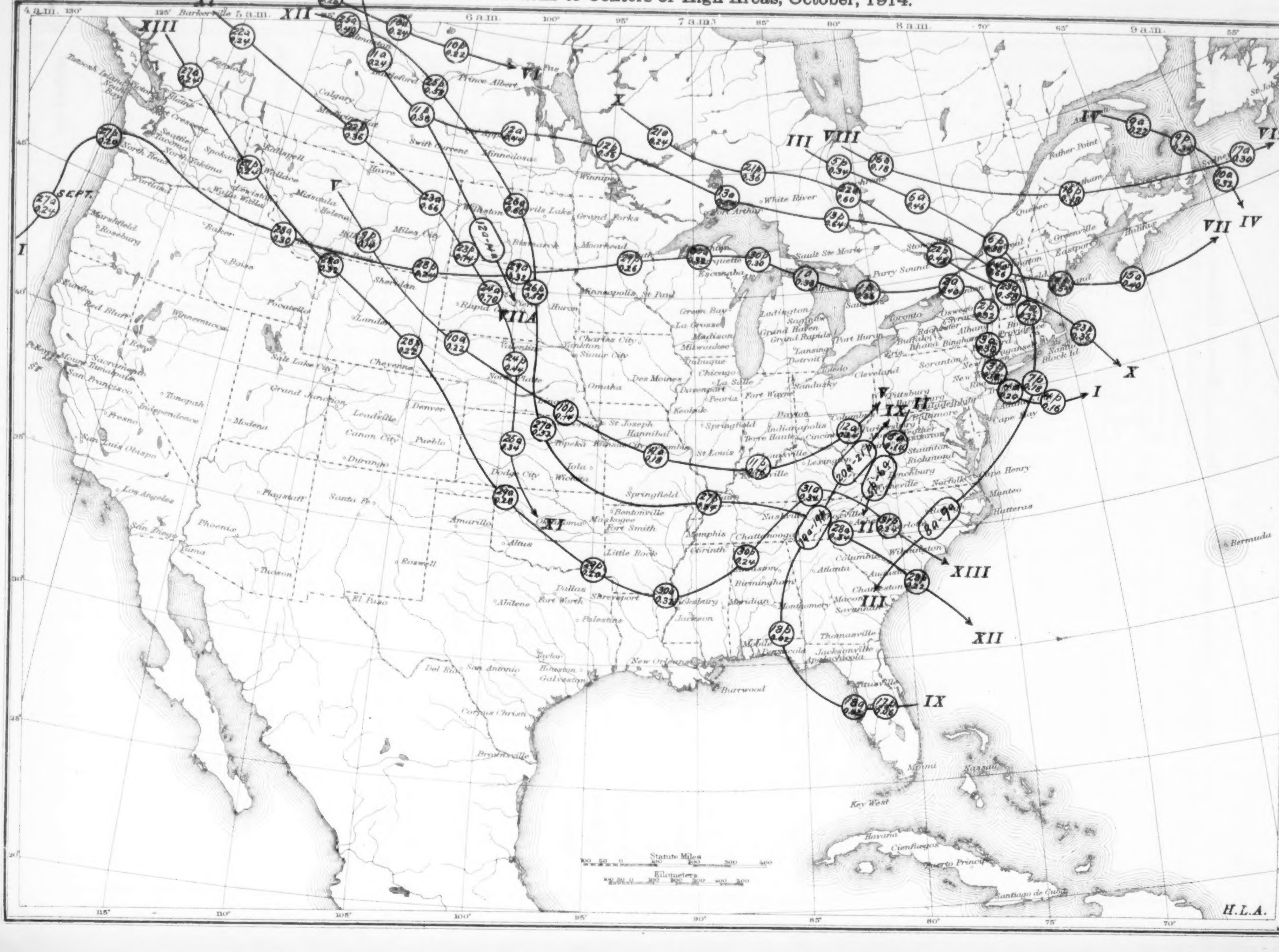

Chart III. Tracks of Centers of Low Areas, October, 1914.

Chart IV. Departure of the Mean Temperature from the Normal, October, 1914

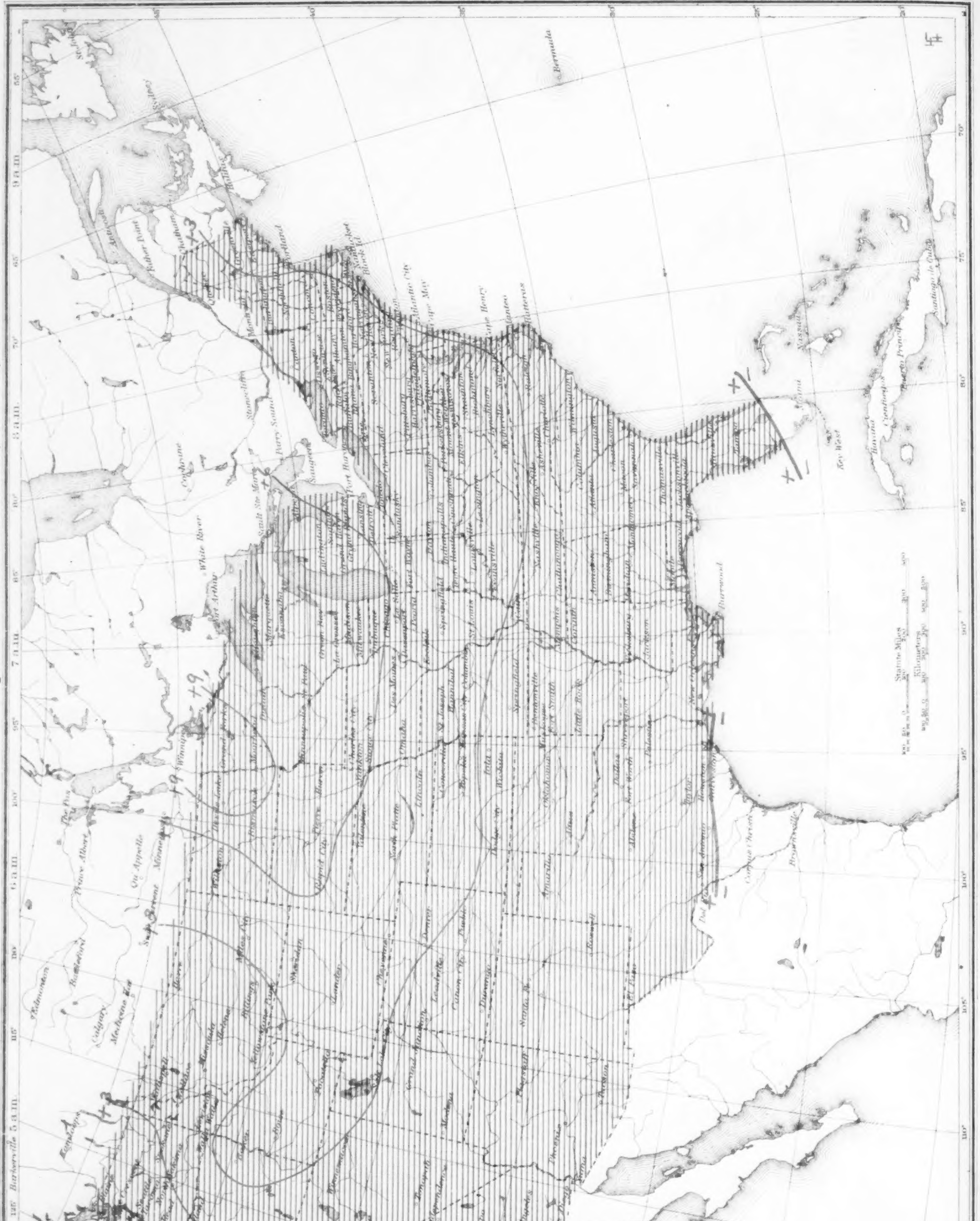

Chart V. Total Precipitation, inches, October, 1914.

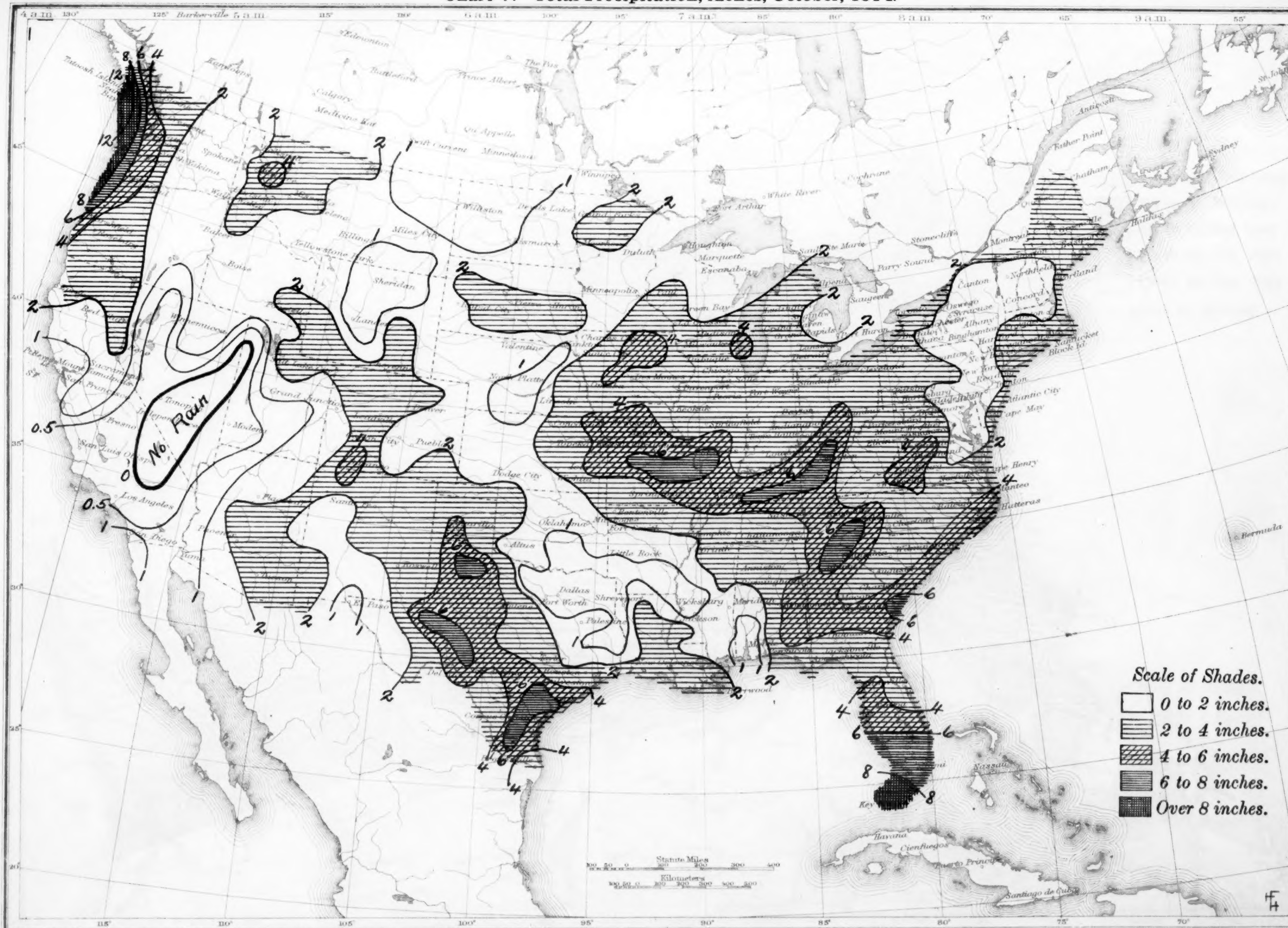

Chart VI. Percentage of Clear Sky between Sunrise and Sunset, October, 1914.

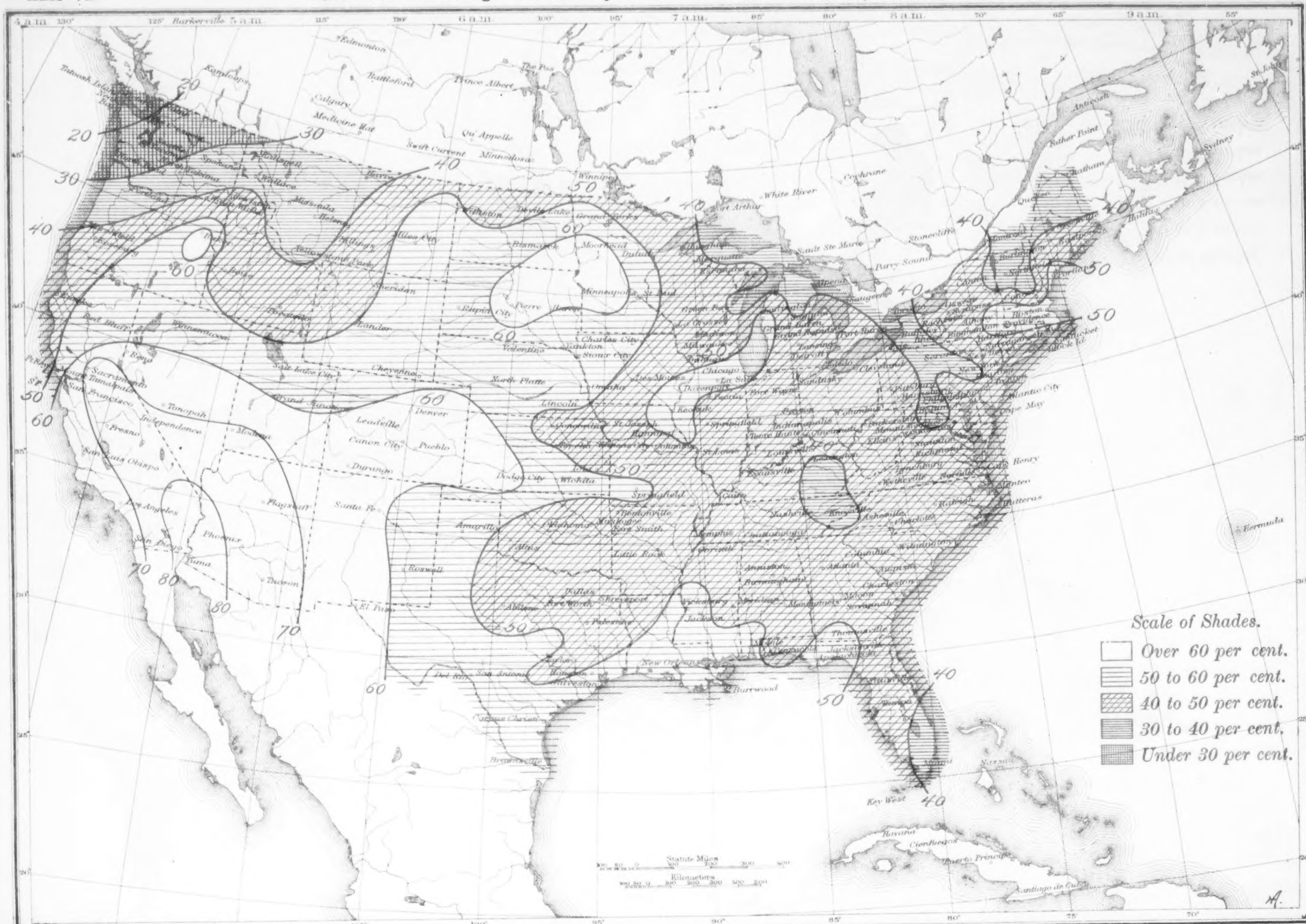

Chart VII. Isobars and Isotherms at Sea Level; Prevailing Winds, October, 1914.